PB 151390

NBS

Technical Note No. 31

Boulder Laboratories

AN ATLAS OF OBLIQUE-INCIDENCE IONOGRAMS

BY VAUGHN AGY, KENNETH DAVIES
AND ROGER SALAMAN

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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November 1959

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INTRODUCTION

This atlas is intended to serve a twofold purpose: first, to provide a compilation of records, of a type becoming standard in the field of ionospheric research, for those workers who are not now familiar with them, and second, to present records which are characteristic of the specific paths used by the National Bureau of Standards for consideration by those using other paths.

To date, NBS sweep-frequency experiments have been carried out over two approximately east-west paths: Sterling, Va. - St. Louis, Mo. (about 1150 km), and Sterling, Va. - Boulder, Colo. (about 2370 km). The experimental data on these paths were taken under the supervision of R. Silberstein and P. G. Sulzer. For each path a midpoint vertical-incidence station was established within about one mile of the geographical midpoint of the great circle path. For the Sterling - St. Louis path the midpoint station was near Batavia, Ohio and for the Sterling - Boulder path it was near Carthage, Illinois. The shorter path was used from August 1951 to December 1952 when the St. Louis equipment was moved west to Boulder. From September 1953 to May 1955, routine records were made over the Sterling-Boulder path, after which time various minor equipment changes were made to improve the time-delay records and to obtain records giving more propagation information for the path.

The data concerning the end-point stations are tabulated below:

Equipment	Power	Time	Sweep Frequency	Pulse Length	Pulse Rep Rate	Antennas
C-3 (modified)	10 kw	12 min*	2-25 Mc	50 μs**	25/sec	Horizontal Rhombic

*Changed in 1955 to $7\frac{1}{2}$ minutes.
**Unless otherwise noted in the body of the atlas.

For the Sterling-St. Louis path the time at which each record was made (indicated below and to the left of each record shown) is 75° West Meridian Time. For the Sterling-Boulder path, 90° West Meridian Time was used. The time given for each oblique-incidence ionogram is that at which the frequency passed upward through 23 Mc (changed to 24 Mc during the first months of 1958).

The relatively slow sweep time allowed for manual adjustment, when necessary, to synchronize the two equipments. The midpoint vertical-incidence equipment operated in normal fashion, sweeping from 1 Mc to 25 Mc in 15 seconds once every 6 minutes and later once every 3 minutes. The 3 minute spacing between sweeps allowed selection of the vertical-incidence ionogram made within $1\frac{1}{2}$ minutes of the time the slower oblique-incidence sweep passed through the frequency of interest, e.g., the MUF.

The oblique-incidence ionograms are plots of time-delay against frequency (on a linear scale). The ordinate (time-delay) scale, however, just as for vertical-incidence ionograms, is calibrated in terms of the apparent virtual half-path. In order to determine the absolute time delay (or virtual half-path) between the two stations at a given frequency, it is necessary to take the arithmetic mean of the ordinates on the two end-point records. For given virtual heights* of reflection, the virtual half-paths are plotted in Figure 1 for the Sterling-St. Louis path and in Figure 2 for the Sterling-Boulder path. In addition to the 1-, 2-, 3-hop modes, the M and N modes are presented involving both F-layer reflections and E-layer reflections (with the E-layer virtual height assumed to be 100 km).

The ionograms for the shorter path usually show vertical-incidence as well as oblique-incidence traces; for the longer path, however, in order to avoid undue compression of the virtual half-path scale, the first 1000 km of half-path are not recorded. On some of the later records, one or both scales are expanded in order to allow examination of some of the detailed structure of the recorded traces.

In some cases (e.g. Section I-3) the midpoint vertical-incidence records are included for comparison. Although not always labeled, these records are easily identified by the logarithmic frequency scale. The end-point records, unless otherwise noted, were those made at the western terminus of the path, i.e. St. Louis for the shorter path and Boulder for the longer path. The primary reason for this choice is the fact that these records usually are freer of interference than those made at Sterling.

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*Virtual height in this sense, for the 1-hop mode, is the height above a spherical earth of the apex of an isosceles triangle whose base is the chord between the two stations and whose legs are equal in length to the absolute virtual half-path between the stations.

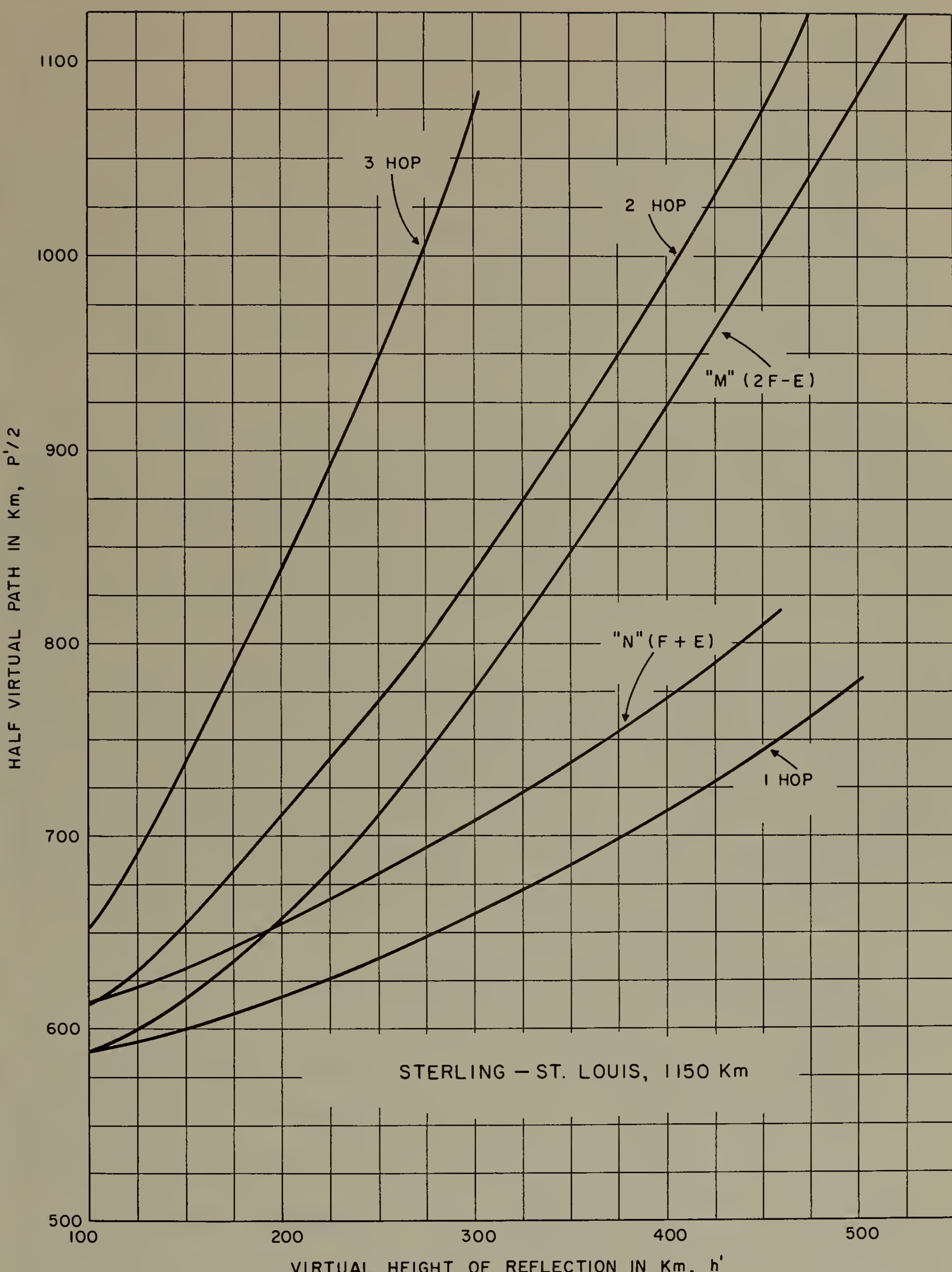
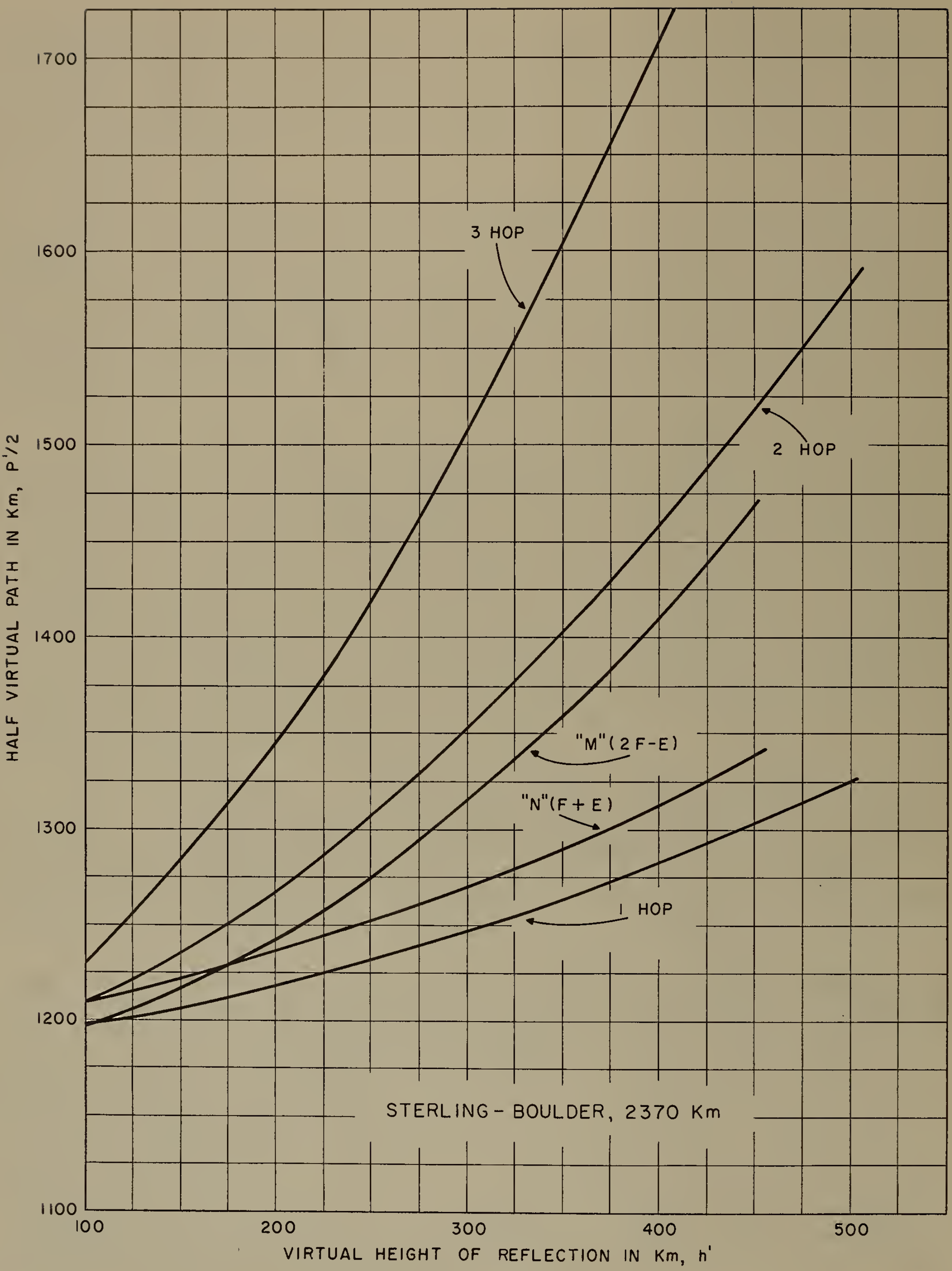

1100
1000
900
800
700
600
500
HALF VIRTUAL PATH IN Km, P'/2
3 HOP
2 HOP
"M" (2F-E)
"N" (F + E)
1 HOP
STERLING — ST. LOUIS, 1150 Km
100
200
300
400
500
VIRTUAL HEIGHT OF REFLECTION IN Km, h'

FIGURE 1



1700
1600
1500
1400
1300
1200
1100
100
200
300
400
500
HALF VIRTUAL PATH IN Km, P'/2
VIRTUAL HEIGHT OF REFLECTION IN Km, h'
3 HOP
2 HOP
"M"(2F-E)
"N"(F+E)
1 HOP
STERLING - BOULDER, 2370 Km

FIGURE 2

The body of the atlas is divided into three parts, giving examples of records made: (1) over the Sterling-St. Louis (1150 km) path, (2) over the Sterling-Boulder (2370 km) path during the routine phase of this part of the experiment, and (3) over the Sterling-Boulder path during the more recent phase of the experiment in which equipment changes were made to increase the observable detail in the ionograms and to make measurements of recorded pulse amplitudes. Some sequences of ionograms are included to show the variations during a day, or during shorter periods when the development of a specific phenomenon can be seen. Other single records are included simply to show the occurrence rather than the development of a particular phenomenon. Many of the records for which interpretations are not readily evident are included because of the interest they may arouse. However, it is not the purpose of the atlas to give detailed interpretations of the ionograms shown.

For the most part, the analysis of the records has consisted of a comparison of the MUF determined directly from the oblique-incidence records with that obtained by applying the appropriate Smith transmission curves (see references) to the midpoint vertical-incidence ionograms. It is worth noting that although, on the average, the scaling of MUF from the vertical-incidence midpoint records agrees well with the observed MUF, there are frequent discrepancies in detail. For an eventual understanding of oblique-incidence propagation, the discrepancies are just as important as the cases of close agreement.

The use of various descriptive terms has developed to aid in the description of certain aspects of the oblique-incidence ionograms. One of these terms is "nose", which is suggested by the shape of the trace on an oblique-incidence ionogram indicating the merging of a high-angle and a low-angle ray. It has become customary occasionally to speak of the "junction frequency" or simply the "nose frequency" for a particular layer when referring to the classical MUF for that layer, but when complications arise, as shown in Sections II-3 and III-3, "nose" may also be used to refer to a junction frequency different from the MUF.

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(NBS work of special interest)

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4. P. G. Sulzer, J. Geophys. Research, 60, 411 (1955).

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INDEX OF SELECTIONS

I. Sterling-St. Louis - 1150 km

Sterling-St. Louis

Sequences Showing Diurnal Variations

Winter Day
January 9-10, 1952

$\Sigma K_p = 28\ o$

Equinoctial Day (Spring)
March 5-6, 1952

$\Sigma K_p = 47\ o$

Equinoctial Day (Spring)
April 2, 1952

$\Sigma K_p = 48-$

Summer Day
May 28, 1952

$\Sigma K_p = 38+$

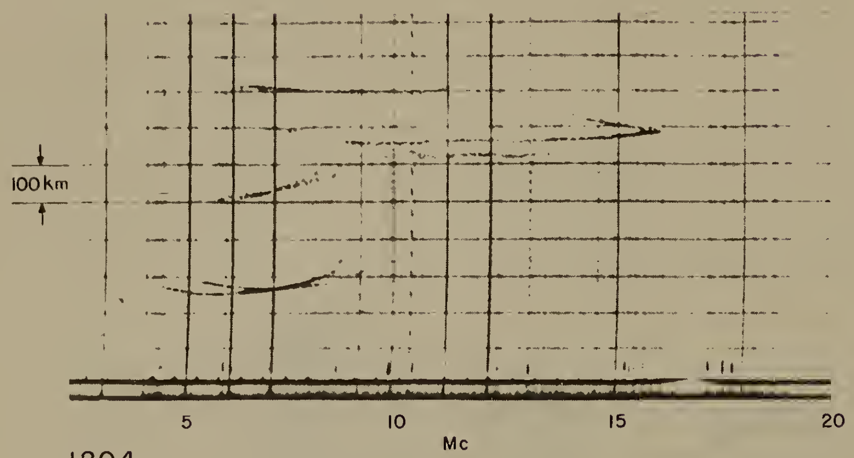
Summer Day
June 25-26, 1952

$\Sigma K_p = 30\ o$

Equinoctial Day (Fall)
September 18-19, 1952

$\Sigma K_p = 8-$

JANUARY 9, 1952



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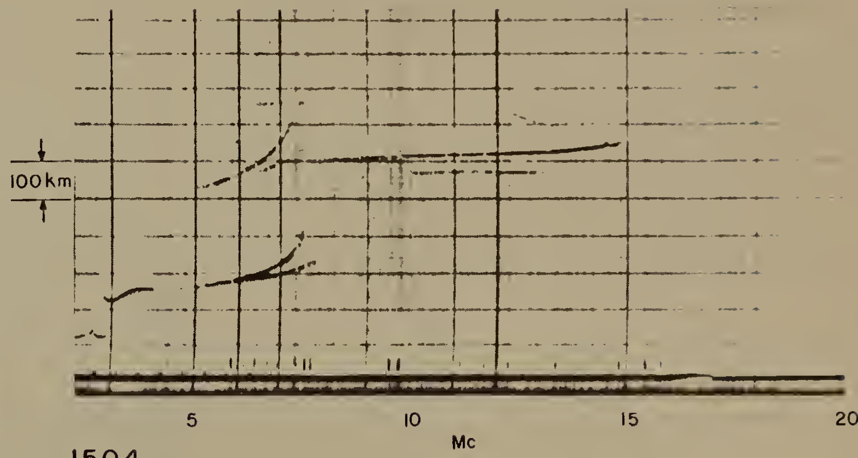

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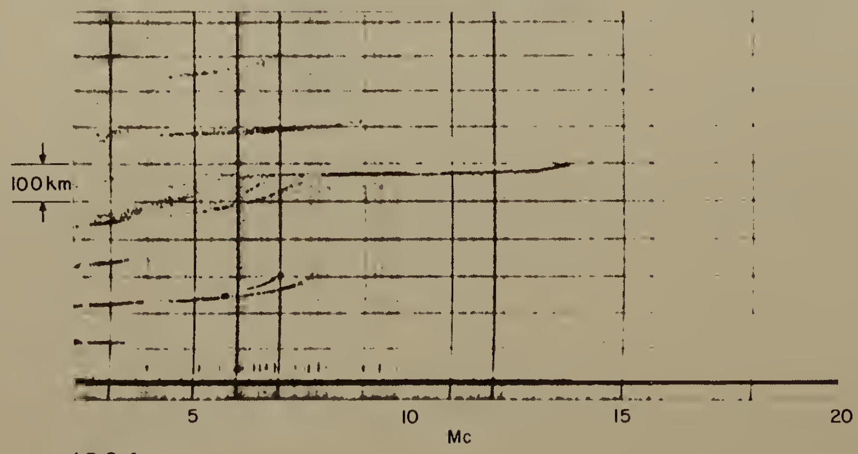

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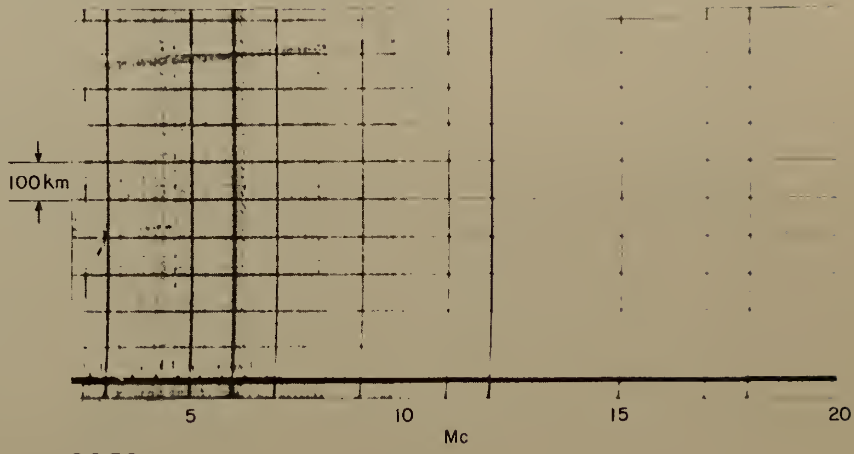

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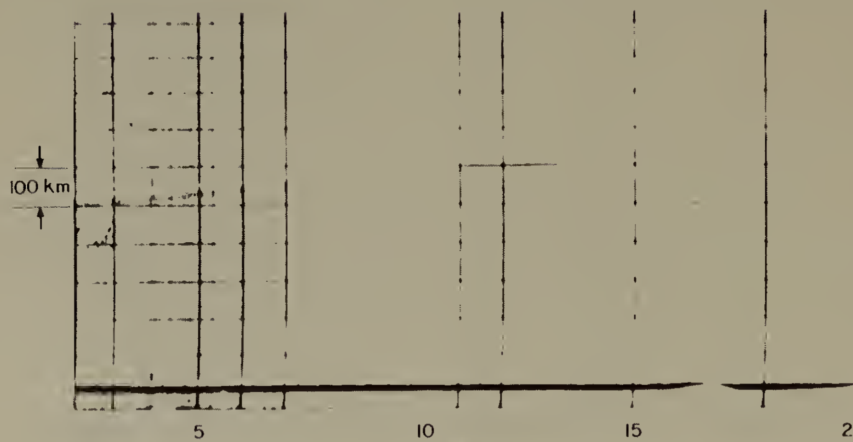

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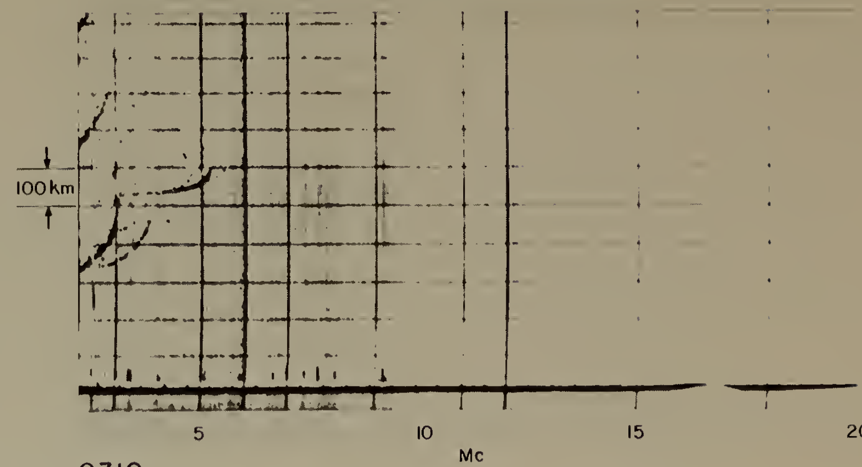

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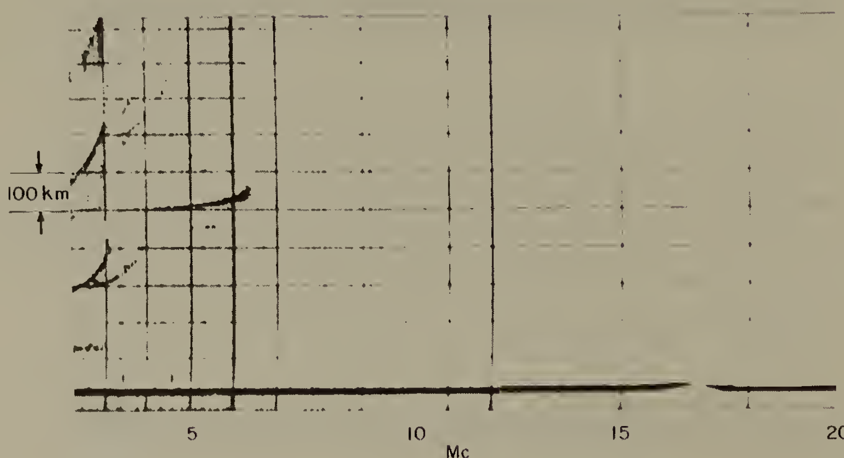

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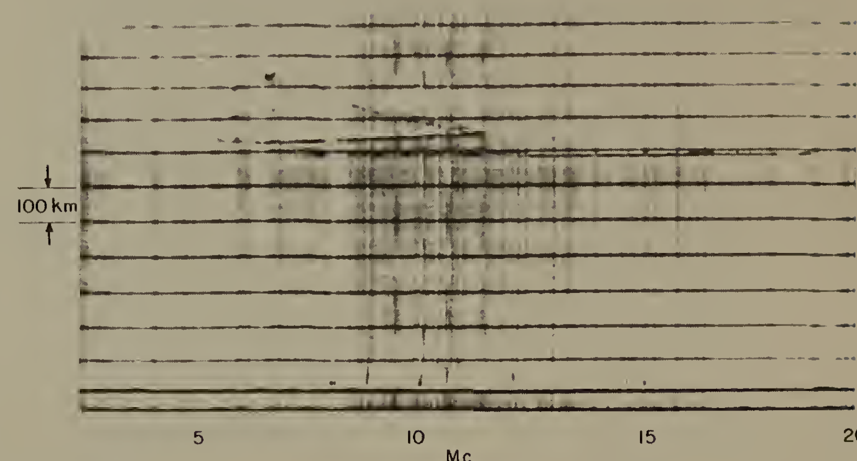

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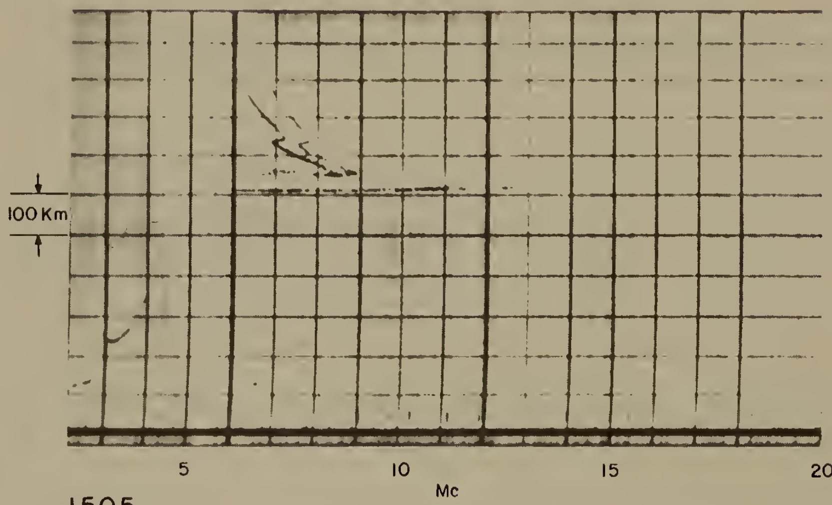
MARCH 5-6, 1952



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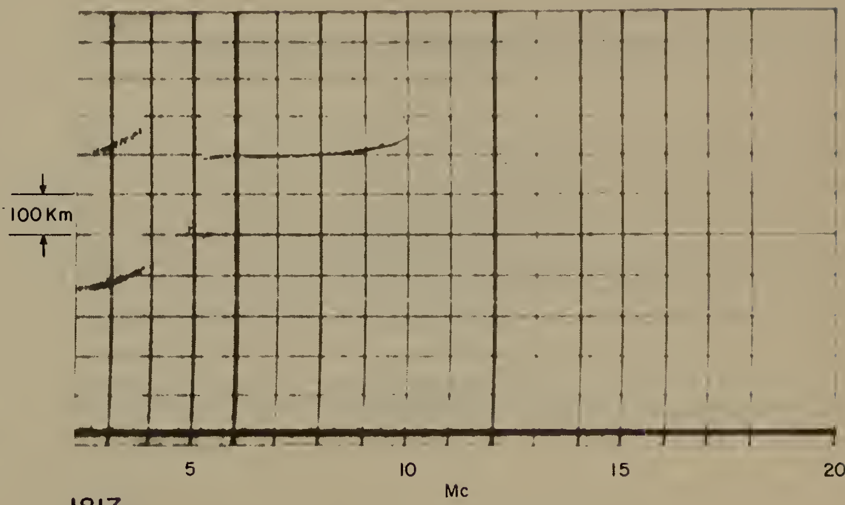

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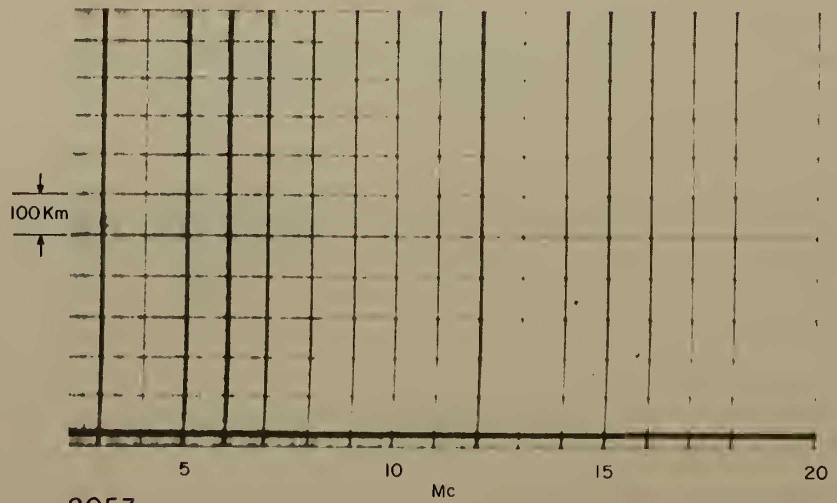

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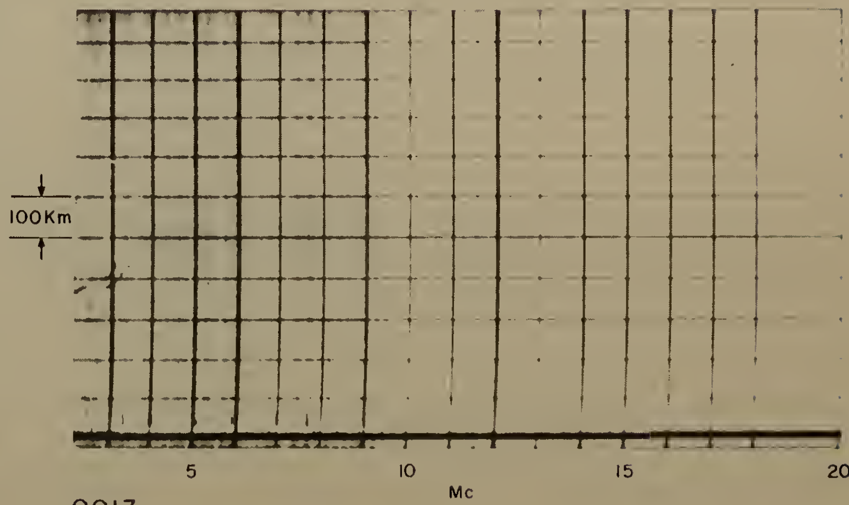

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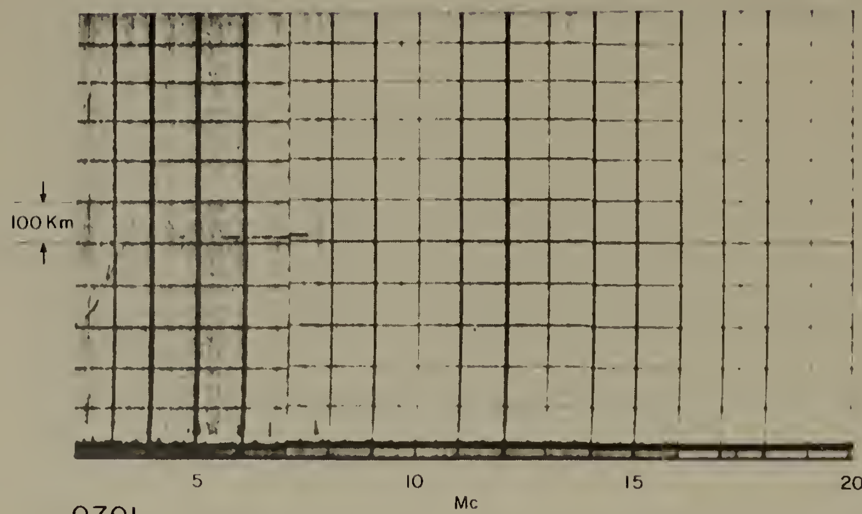

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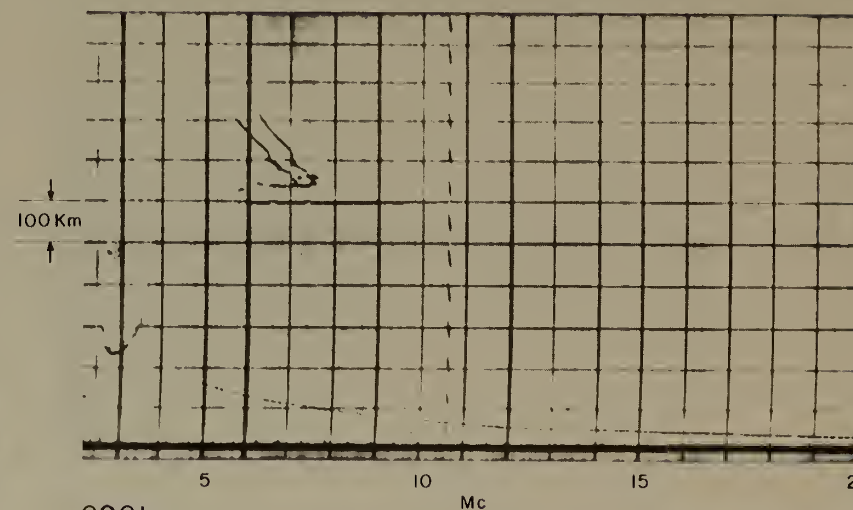

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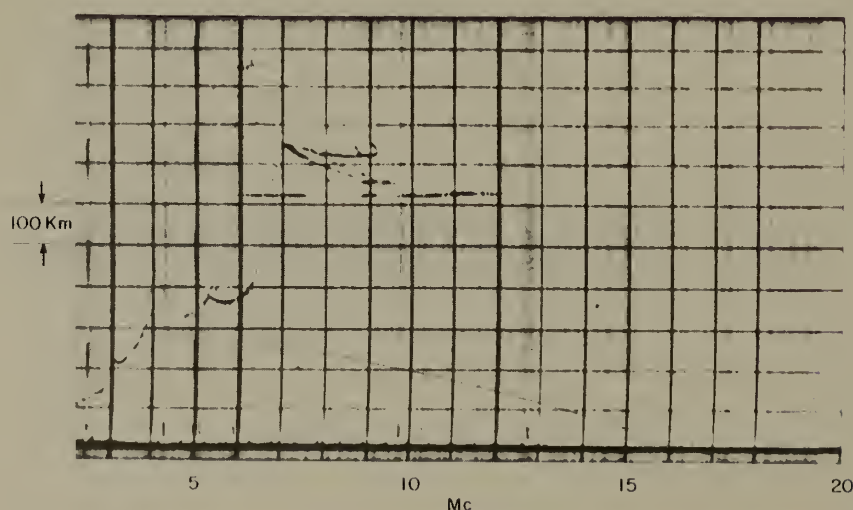

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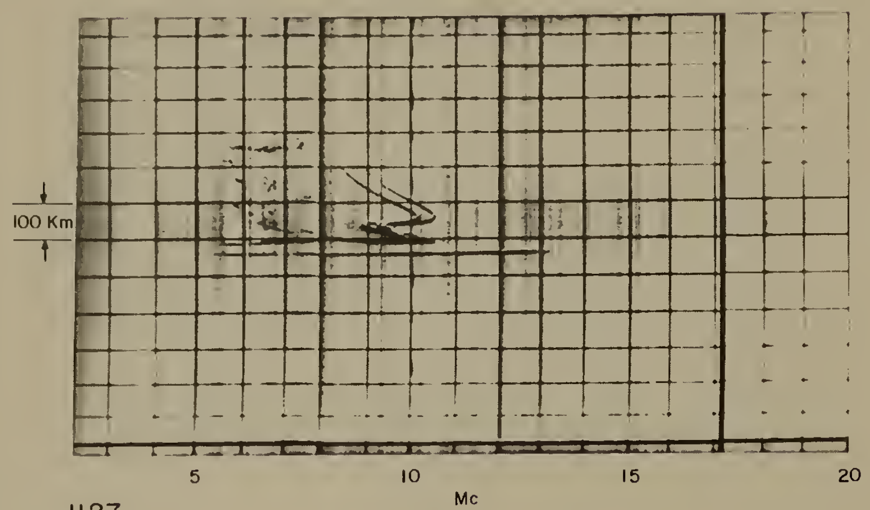

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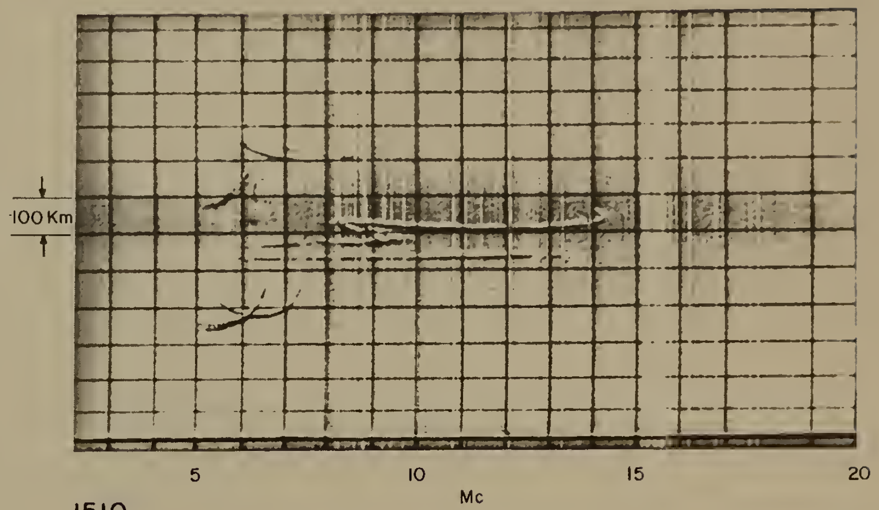

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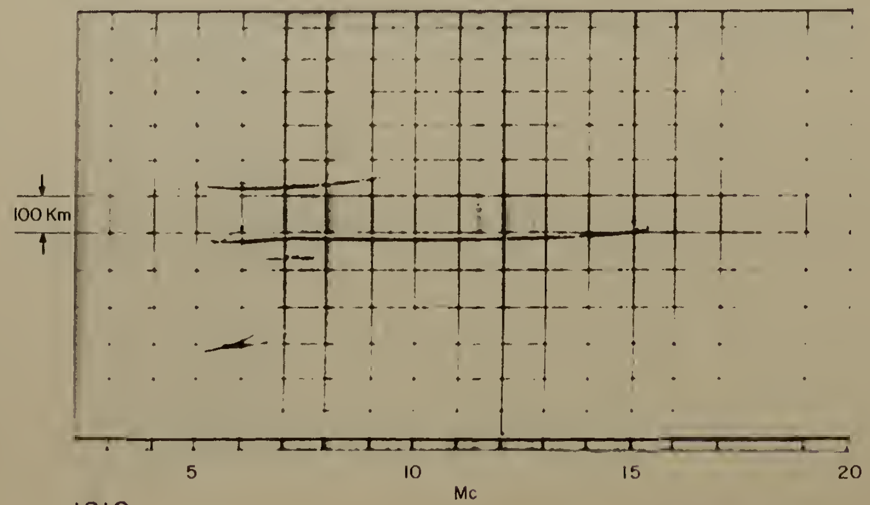

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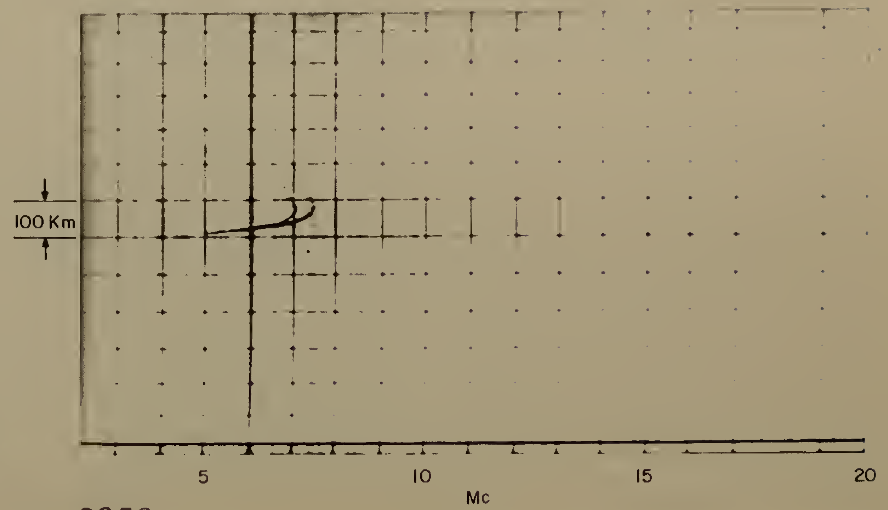

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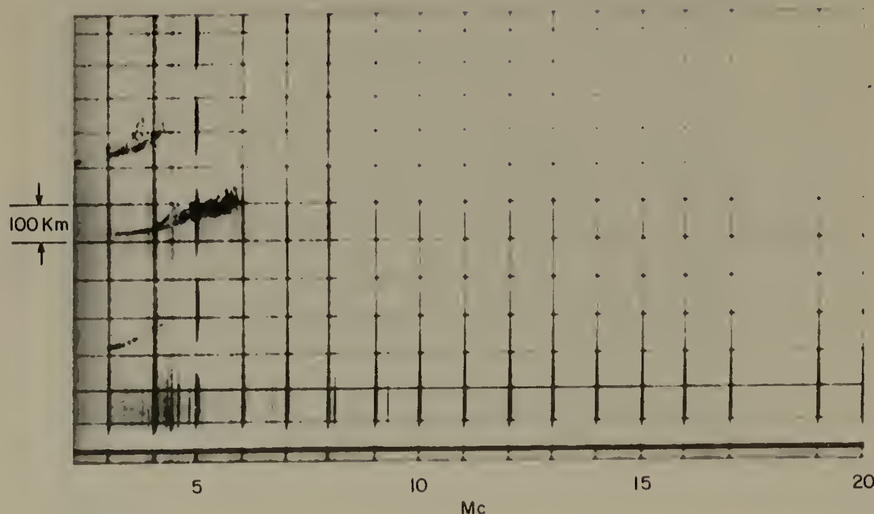

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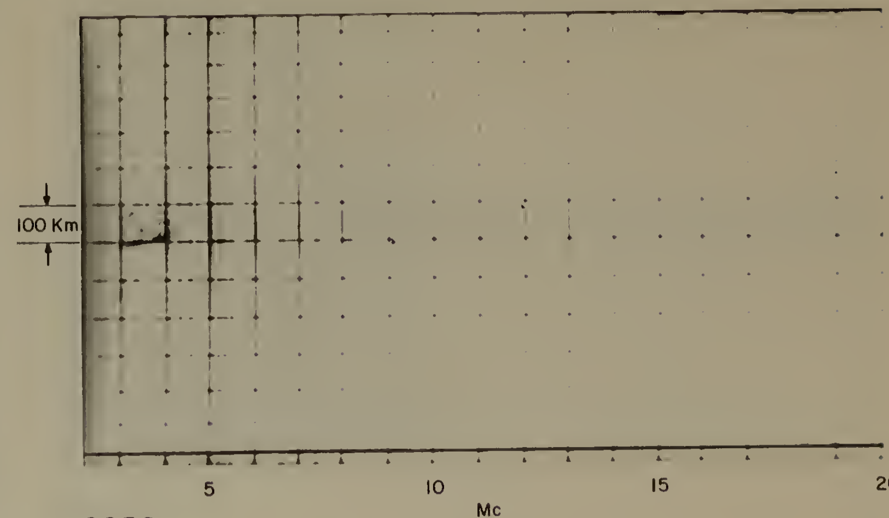

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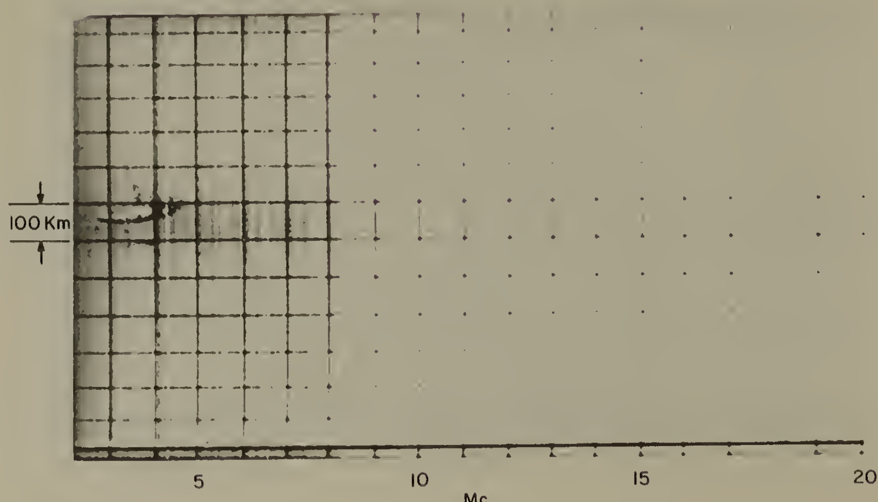

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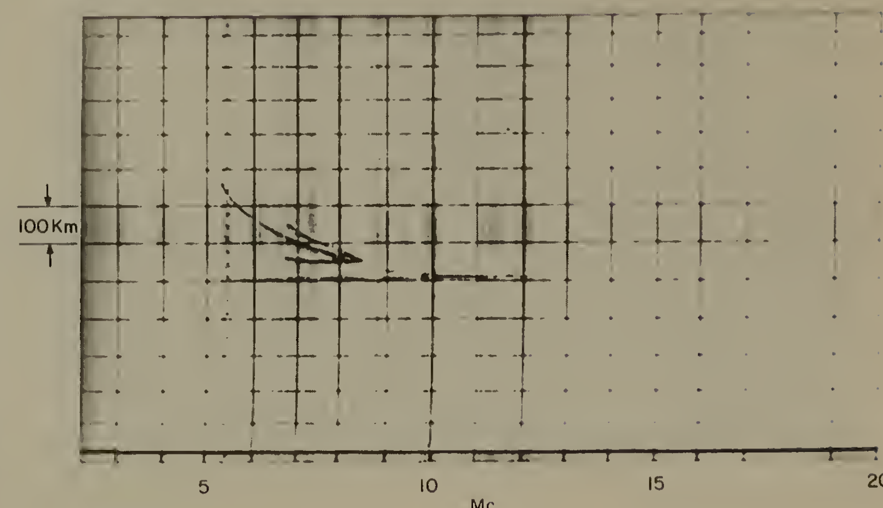

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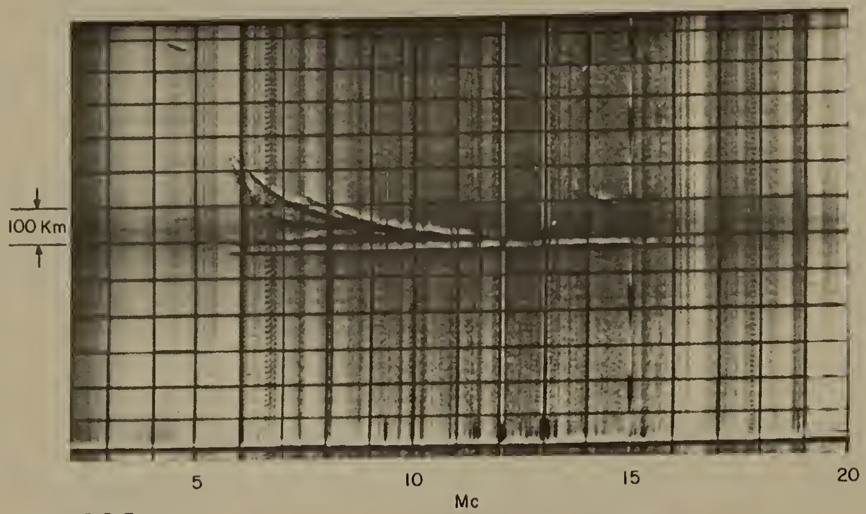

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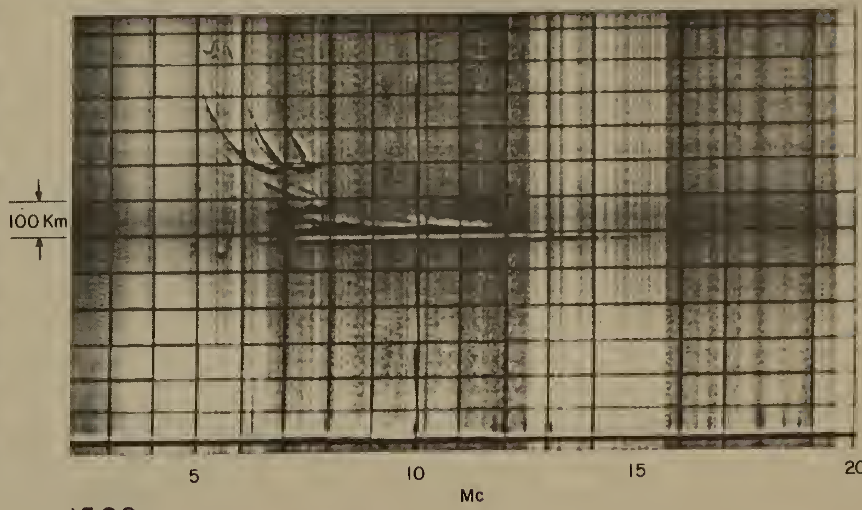

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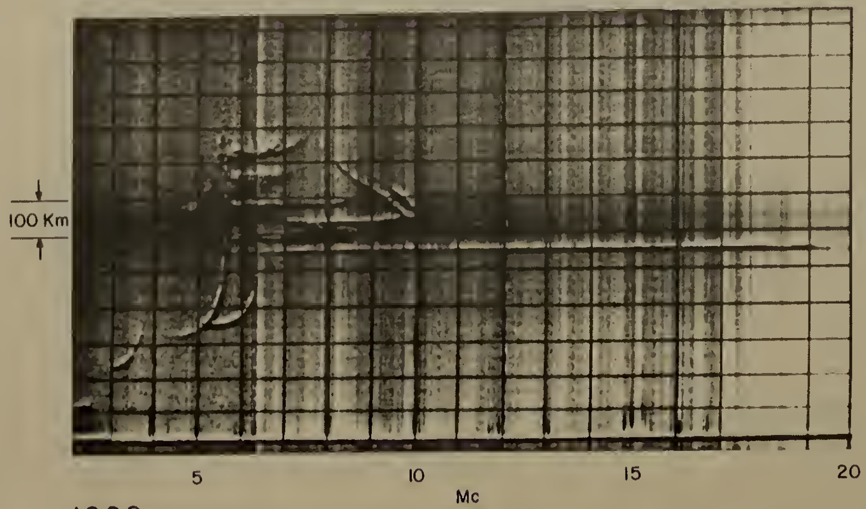

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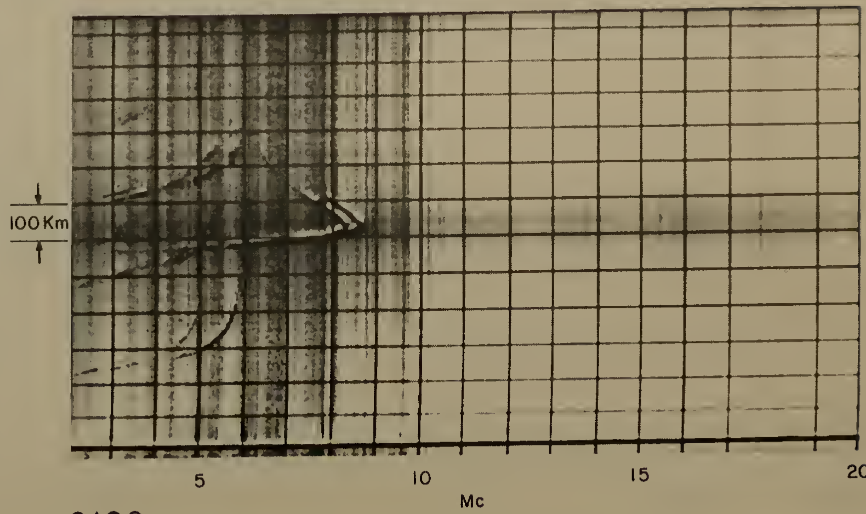

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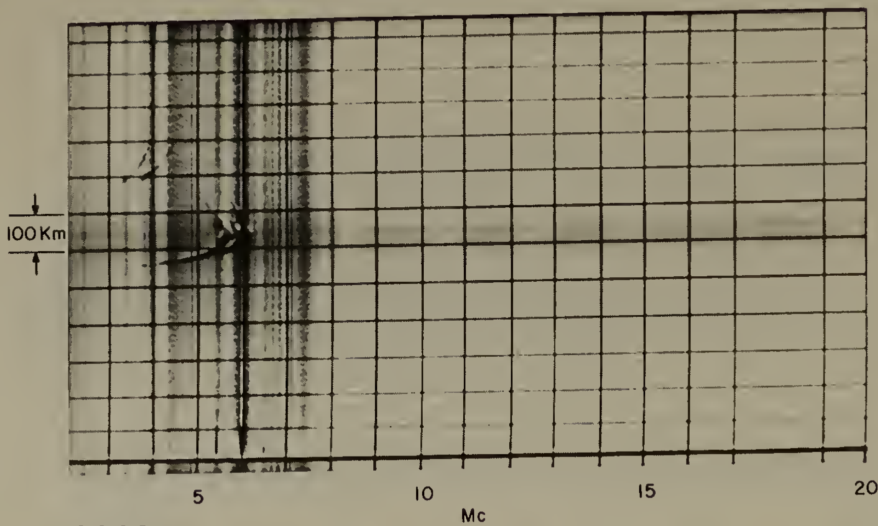

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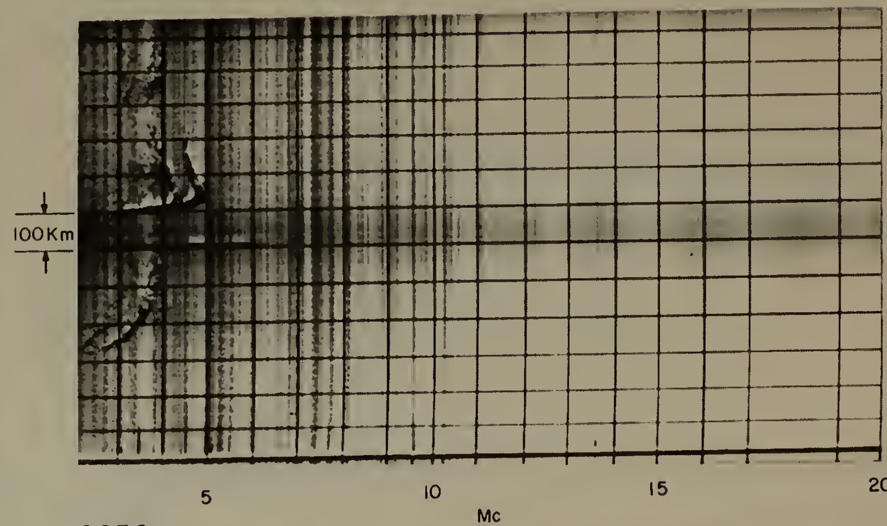

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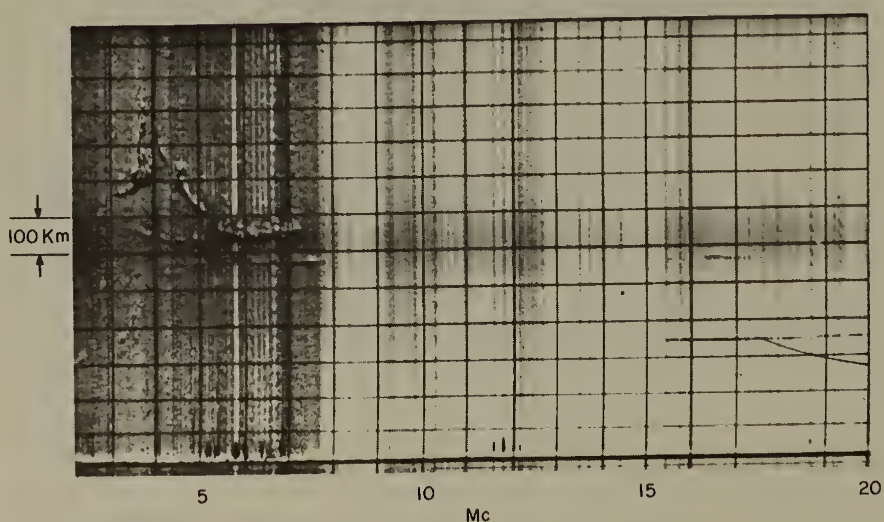

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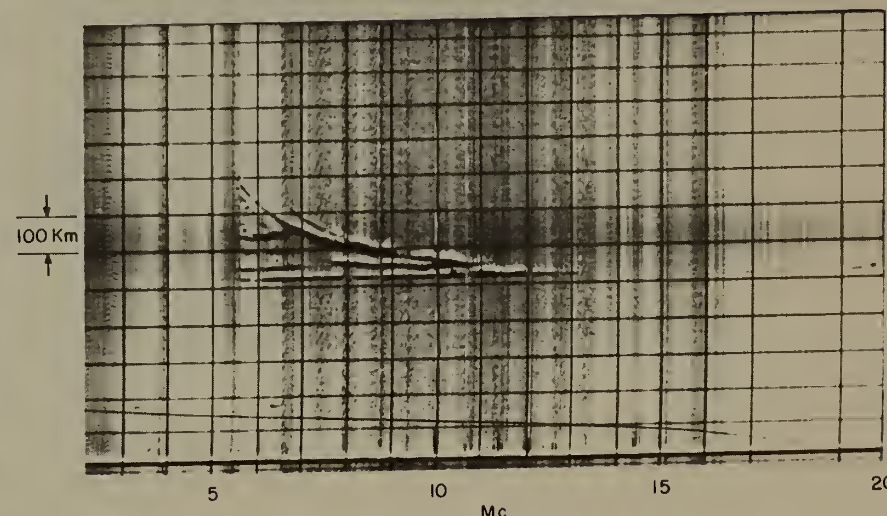

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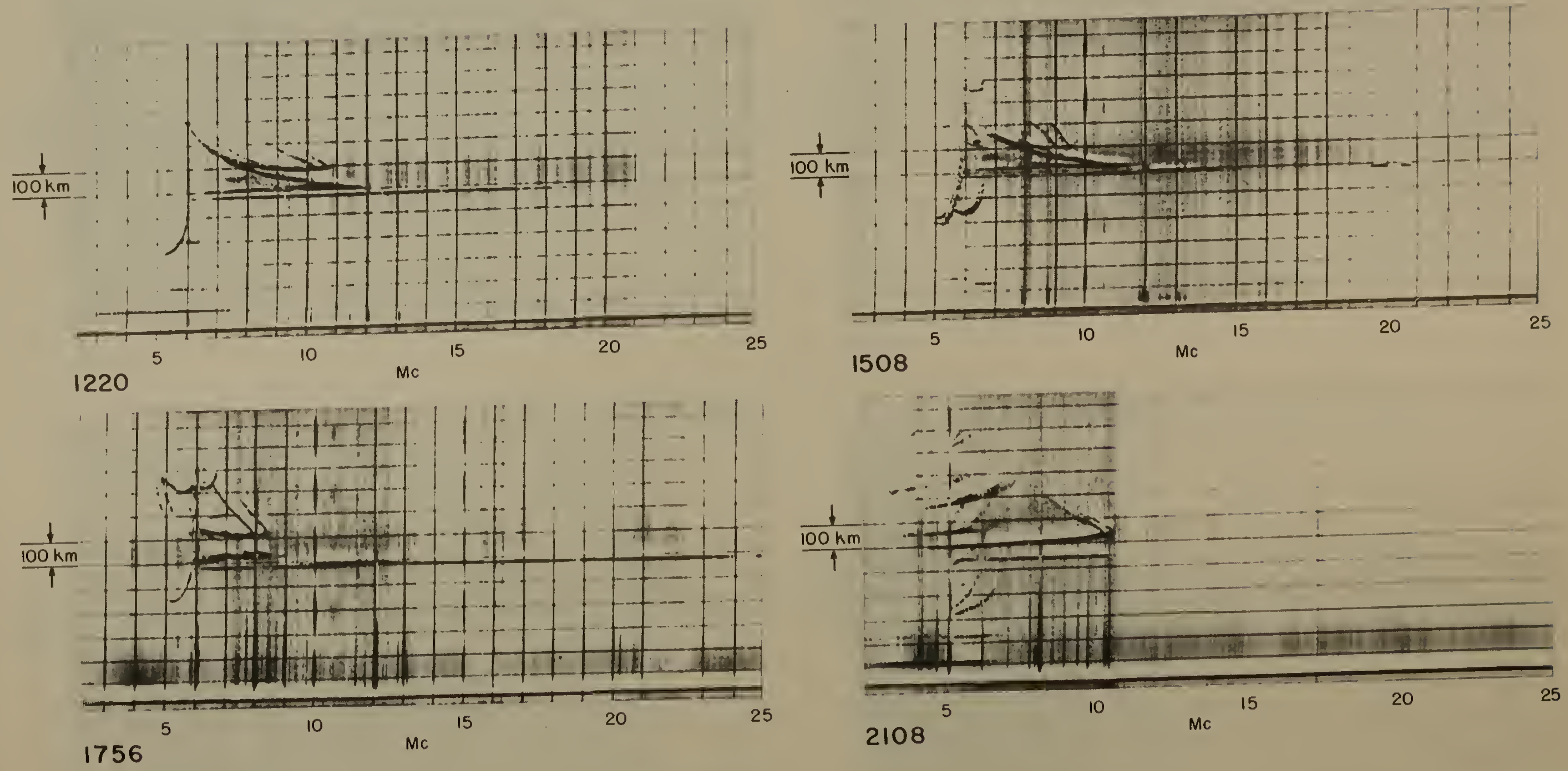

100 km
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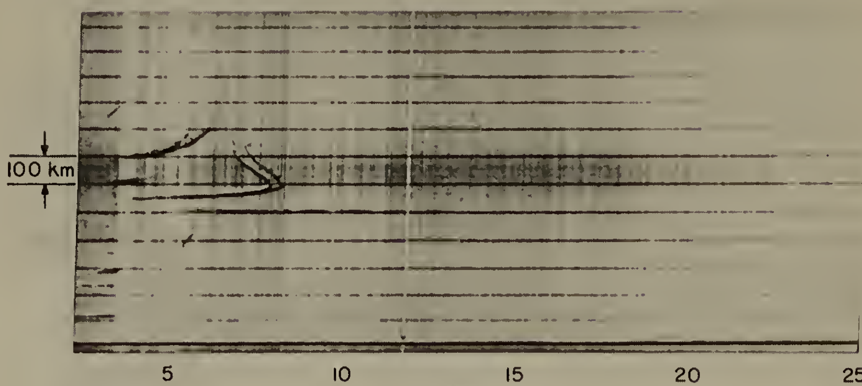

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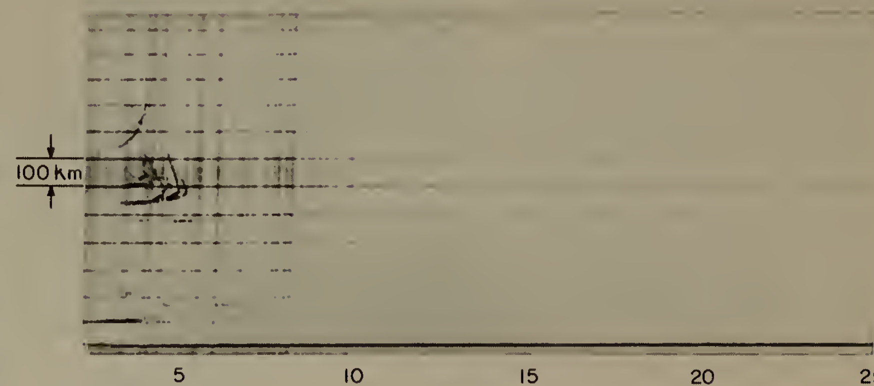

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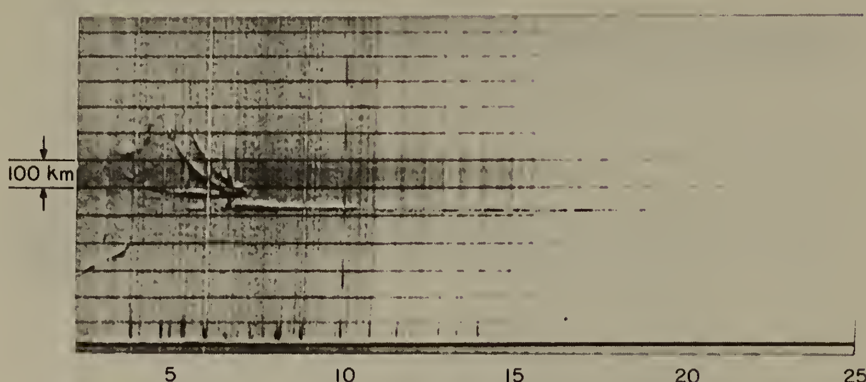

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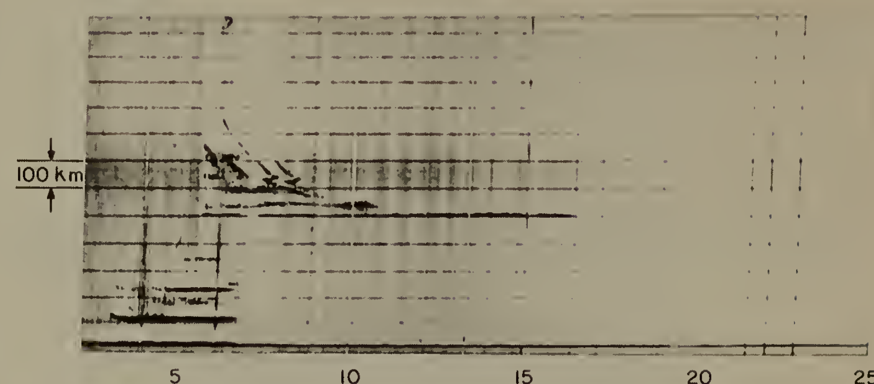

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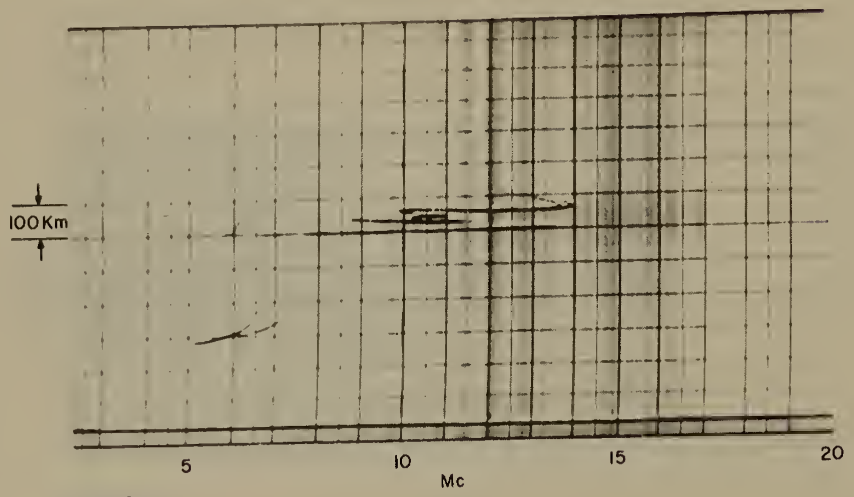

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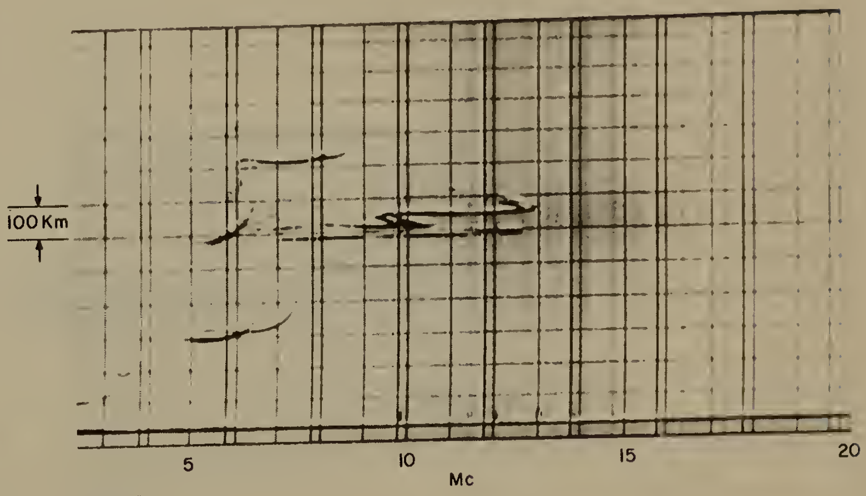

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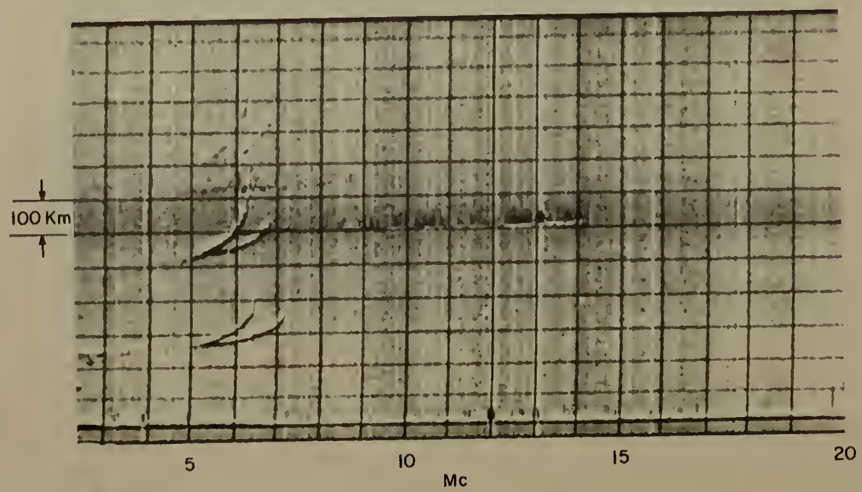

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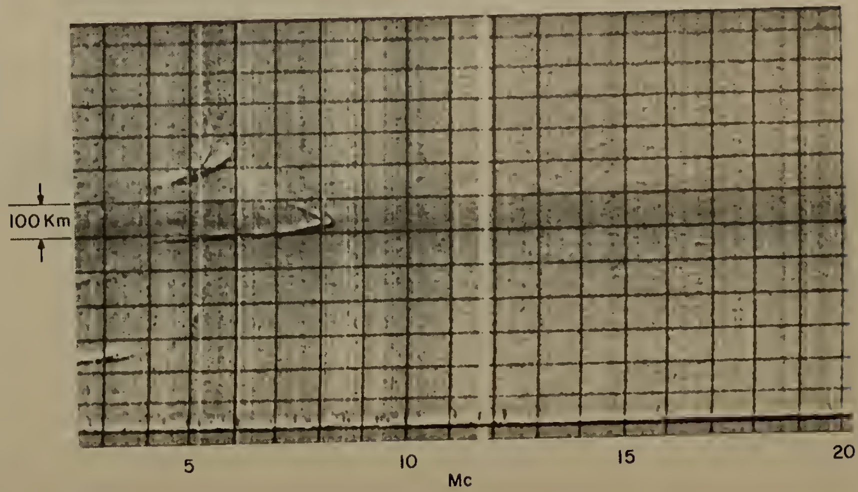

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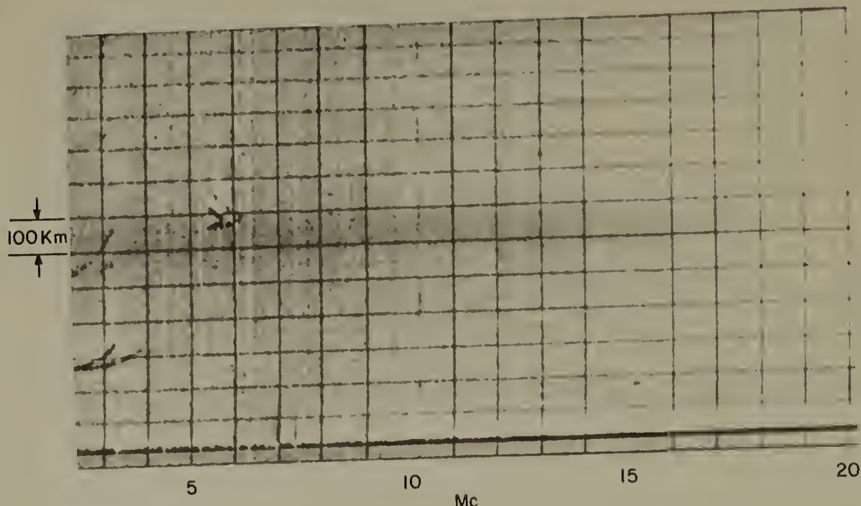

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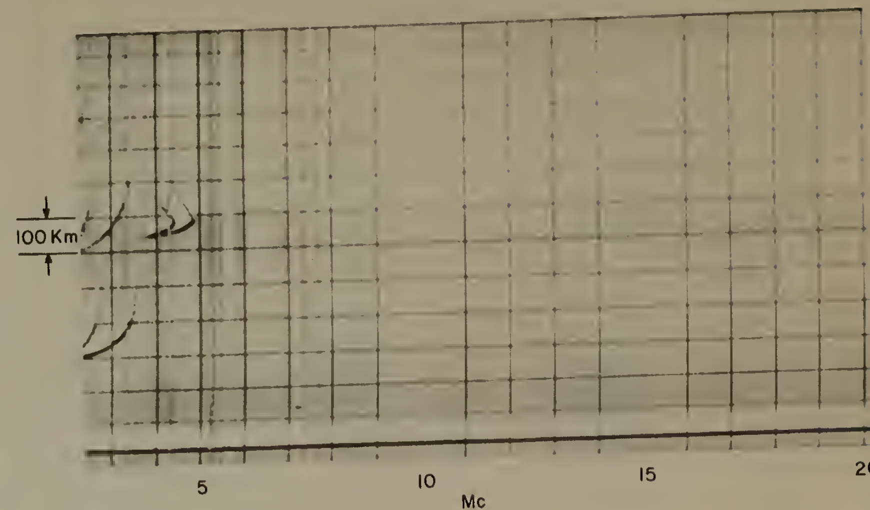

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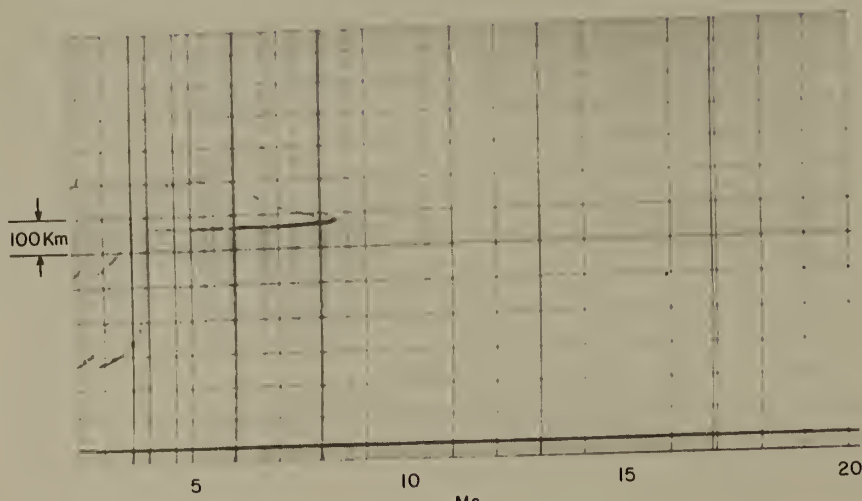

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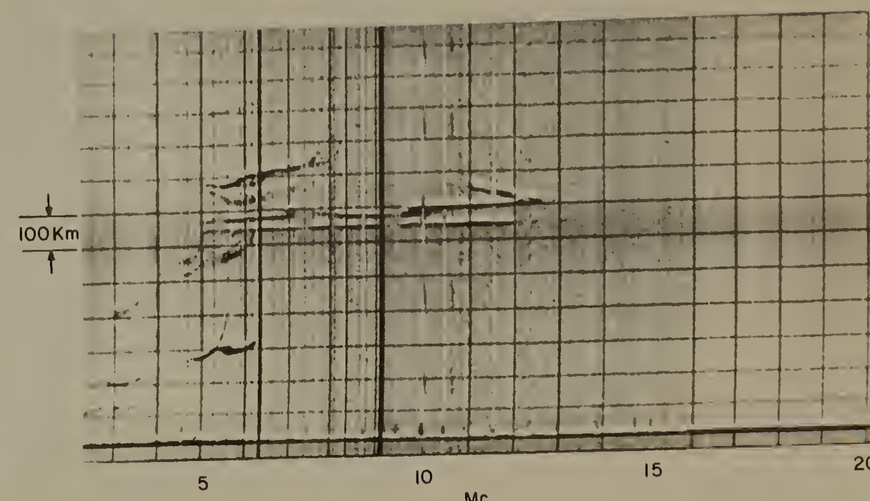

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Sterling-St. Louis

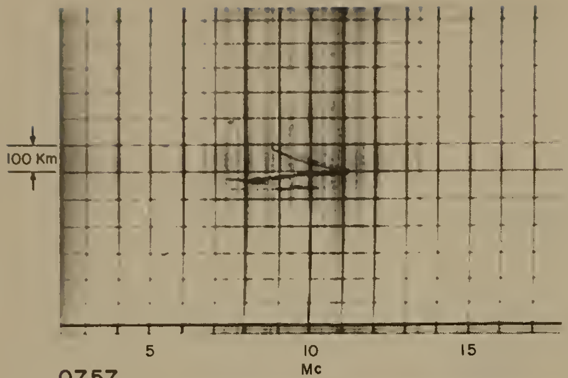
Sequences Showing Development of the F Layers
After Sunrise

April 24, 1952

The F1 trace is seen to develop out of the low angle F2 trace and the night F layer is continuous with the day F2 layer.

May 15, 1952

Here the F2-layer trace develops out of the Pedersen ray trace of the night F layer. The night F layer is continuous with the day F1 layer.



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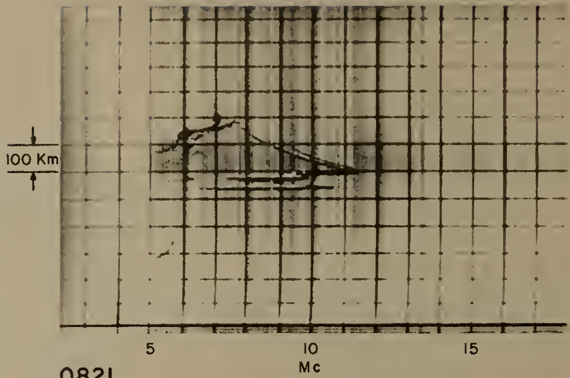
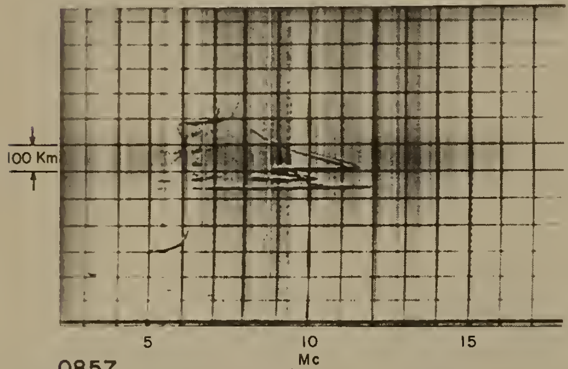


0821



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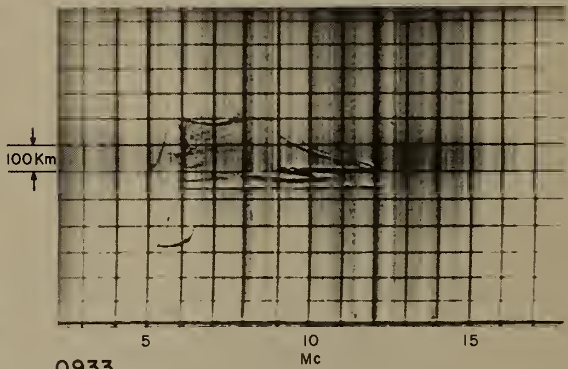
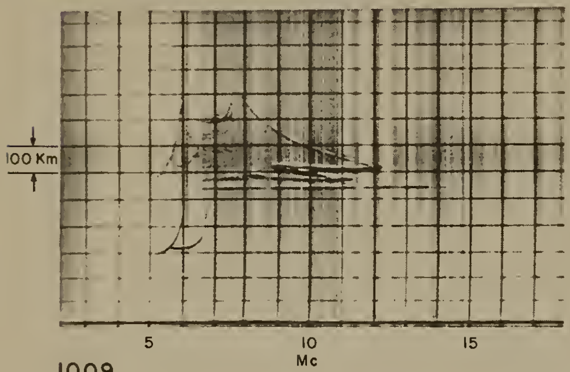
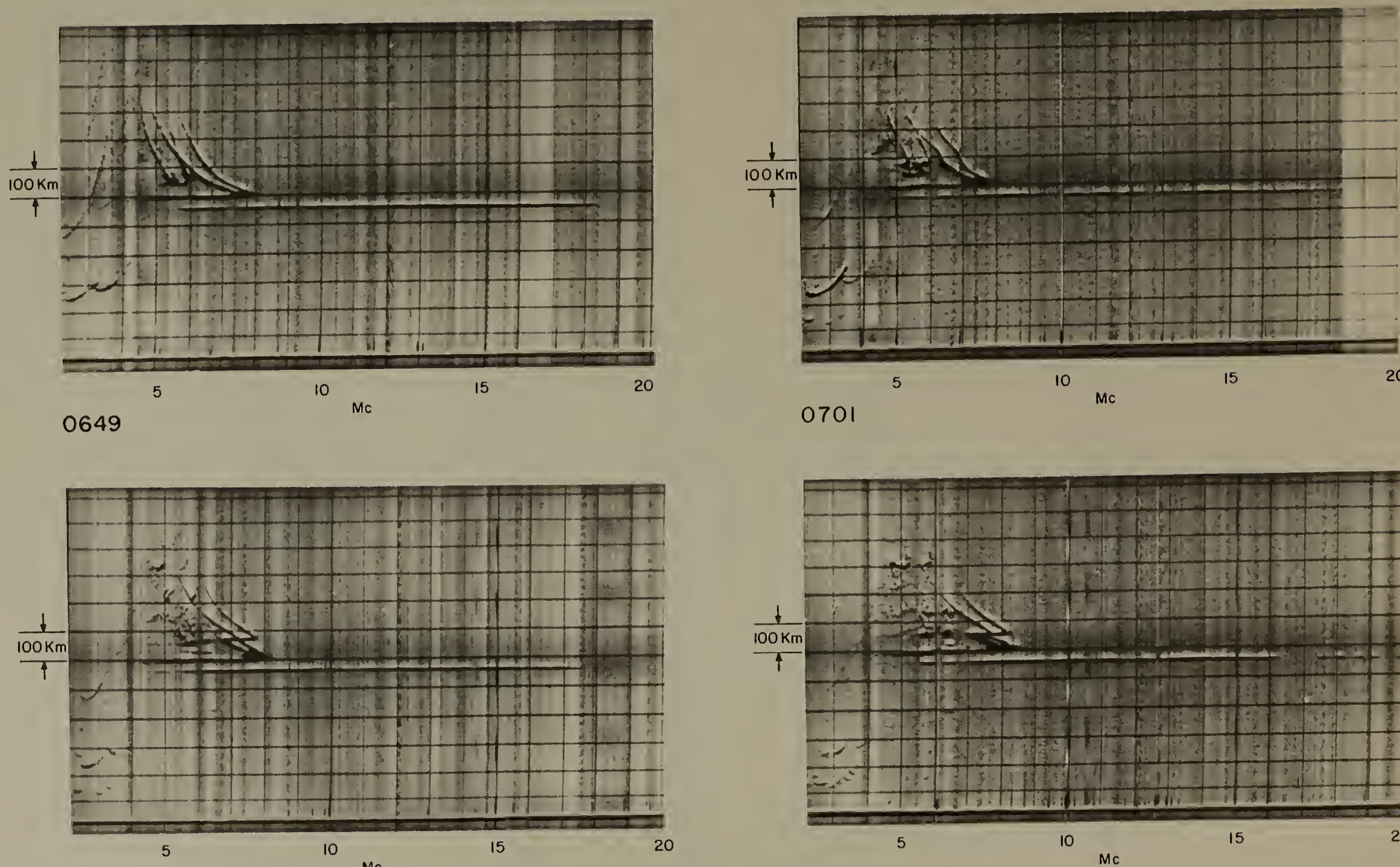


0933



1009

MAY 15, 1952



0649

0701

0713

0725

Sterling-St. Louis

Ionograms Showing Spread Echo

May 1, 1952

The midpoint vertical-incidence record is not only spread but weak, indicating high absorption. The oblique-incidence record is somewhat spread but appears to be relatively strong.

May 29, 1952

On these records spread echoes are evident at vertical incidence but the oblique-incidence traces are relatively sharp.

May 29, 1952

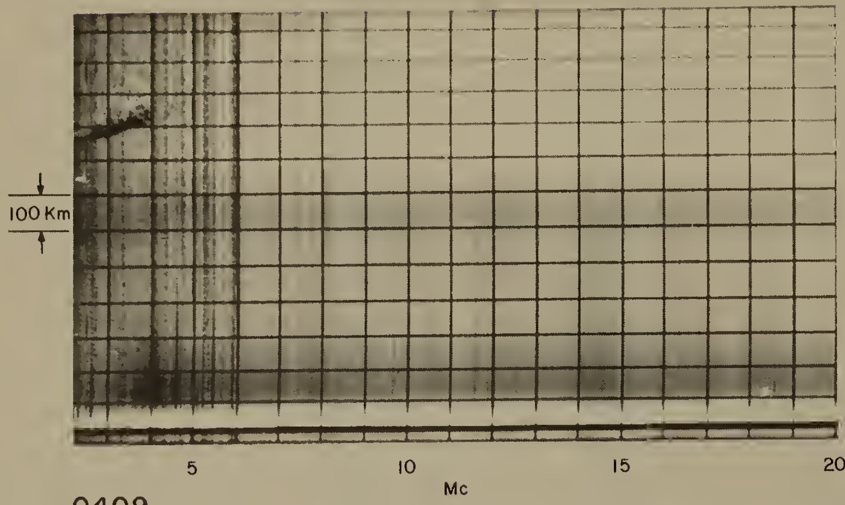
Moderate spread on the oblique-incidence records accompanies severe spread seen at vertical incidence.

The great amount of spread apparent on the midpoint vertical-incidence ionograms represents a complicated ionospheric structure which shows itself in the complex traces seen on the oblique-incidence ionograms.

July 25, October 21, 1952

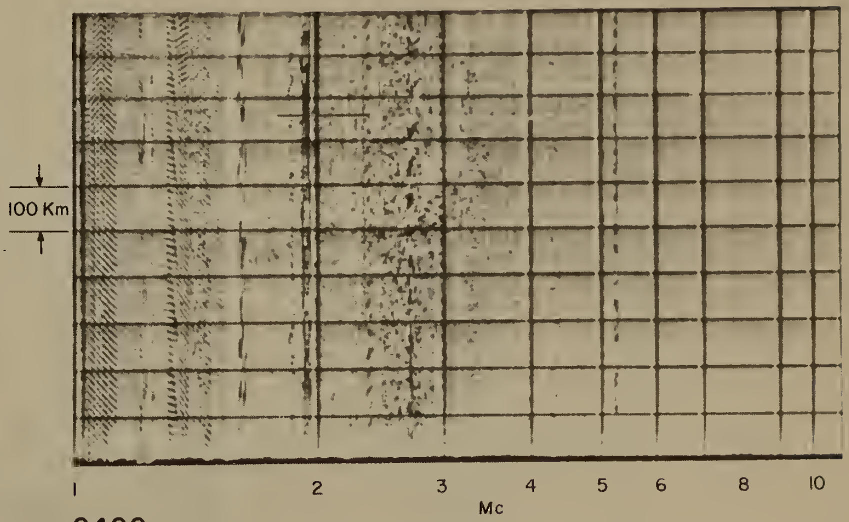
The July 25 ionograms show more spread at oblique incidence than at vertical incidence; the October 21 records show comparable spread.

MAY 1, 1952



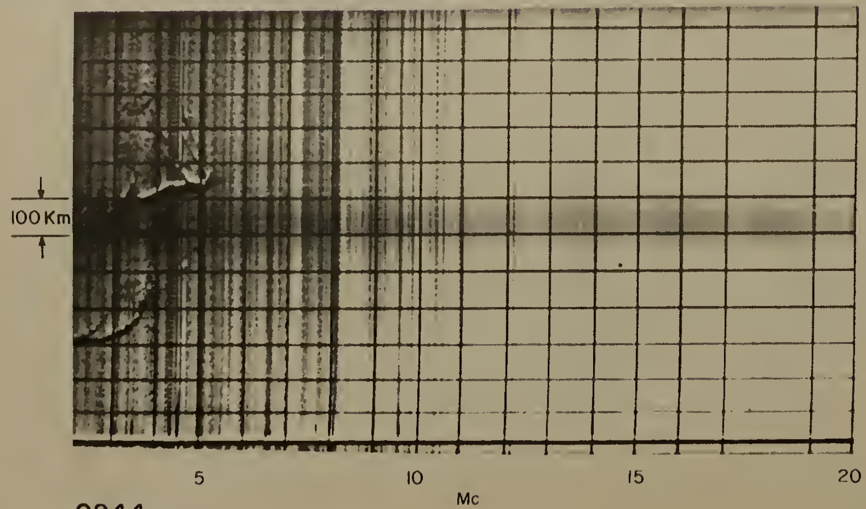
0409

MAY 1, 1952



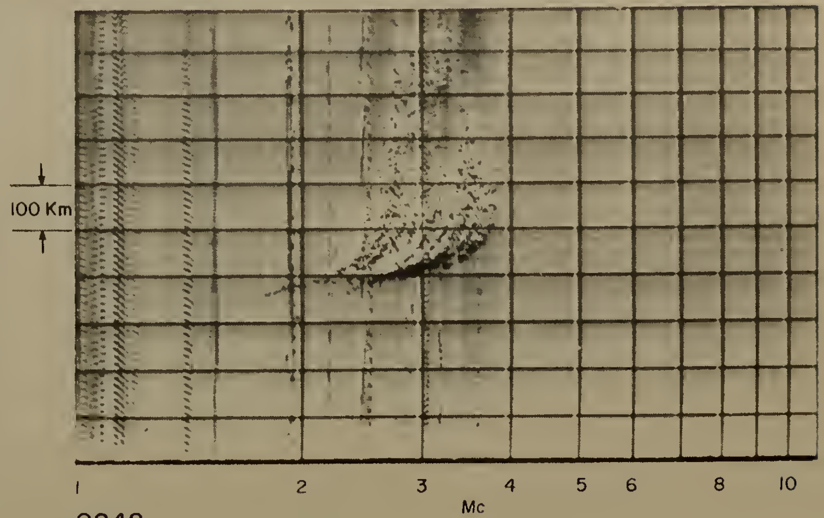
0400

MAY 29, 1952



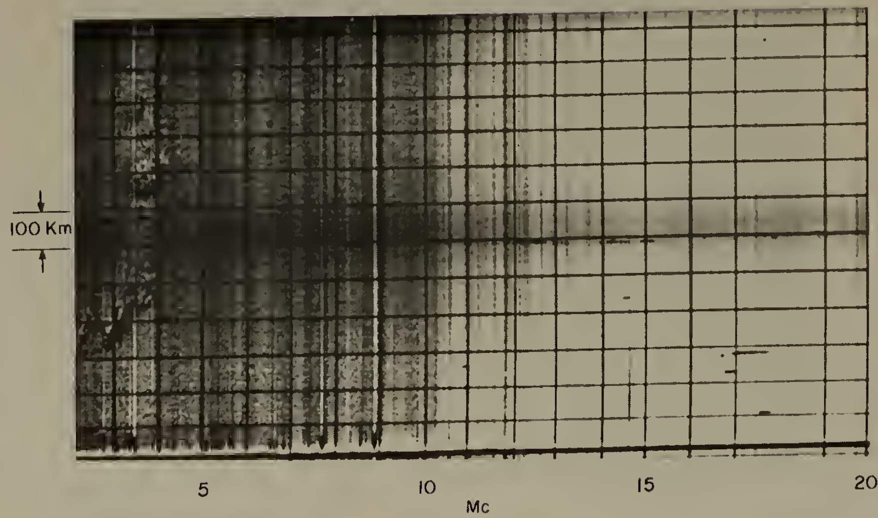
0244

MAY 29, 1952

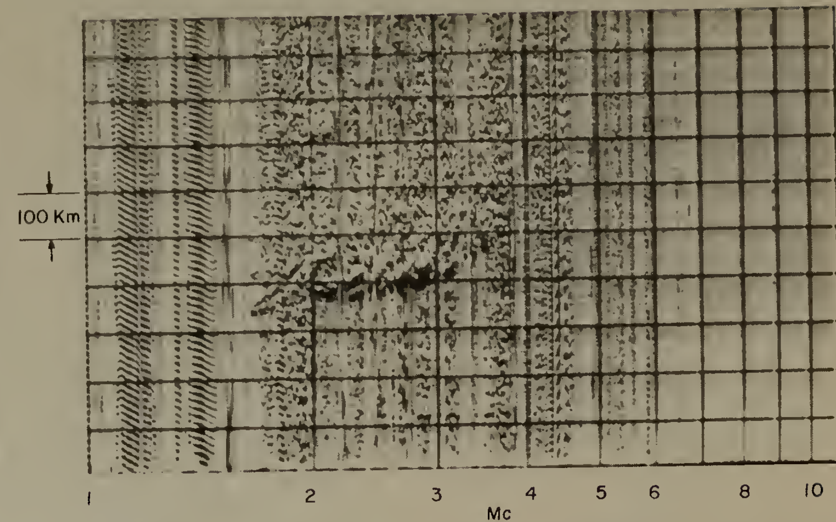


0242

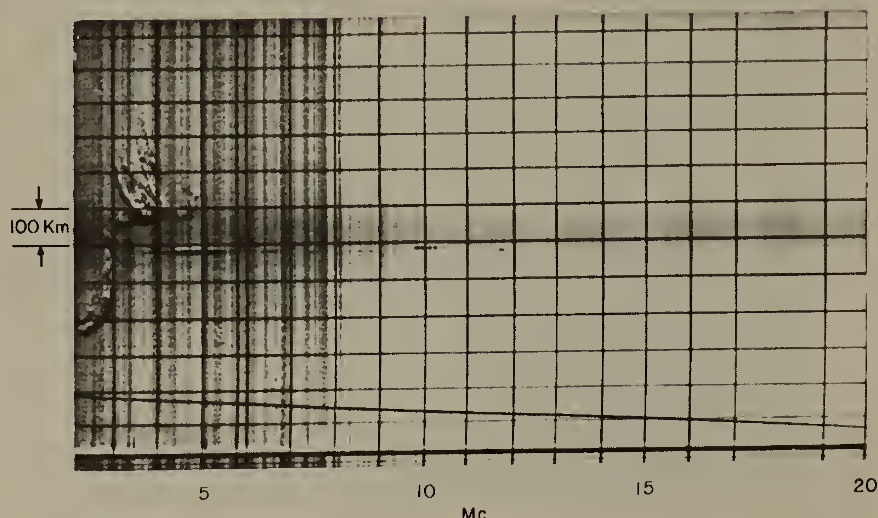
MAY 29, 1952



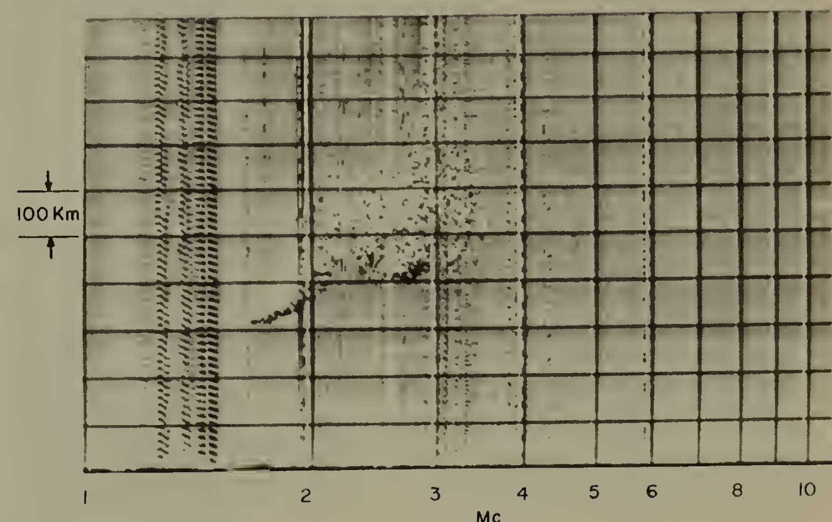
0408



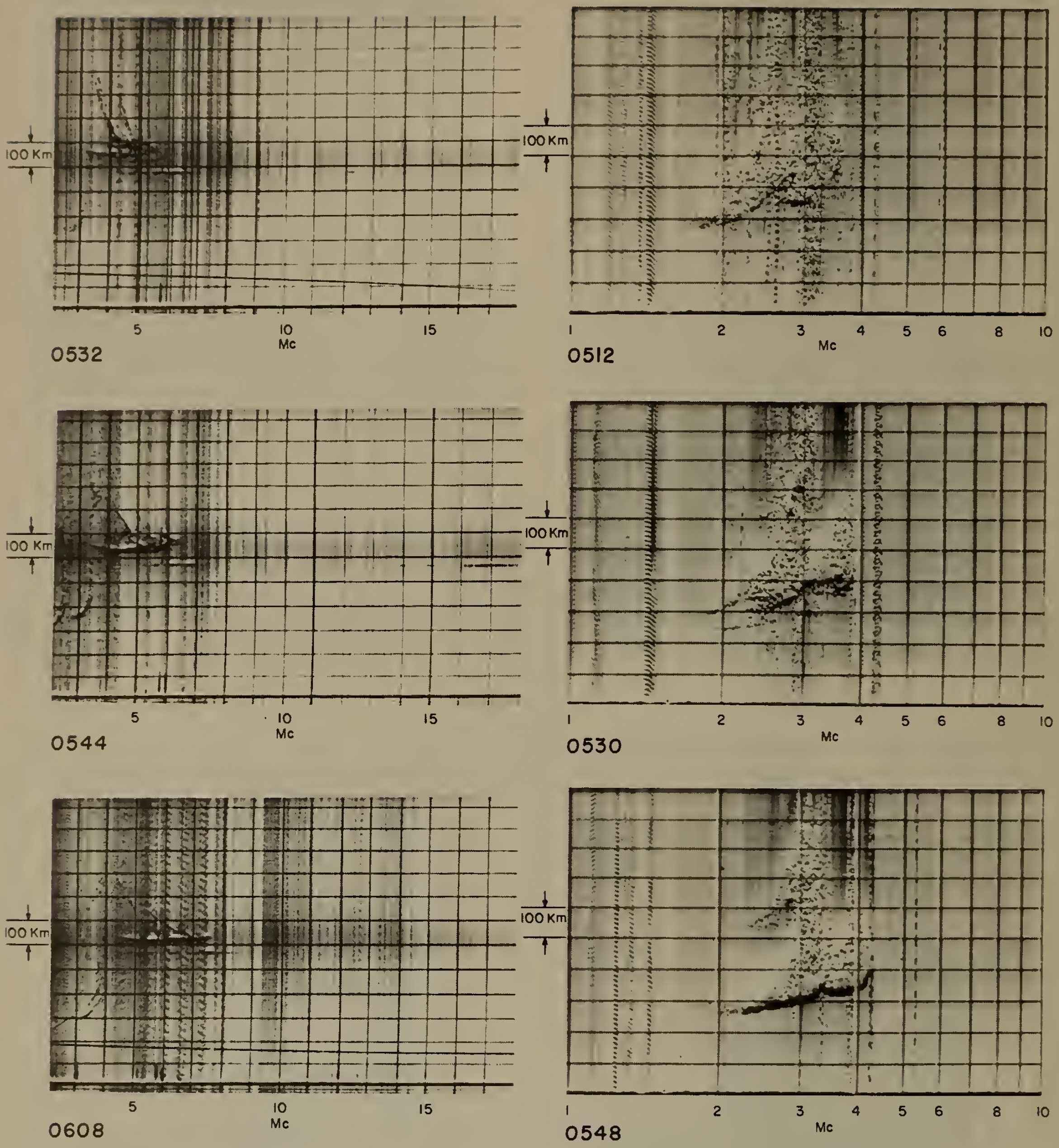
0400



0508

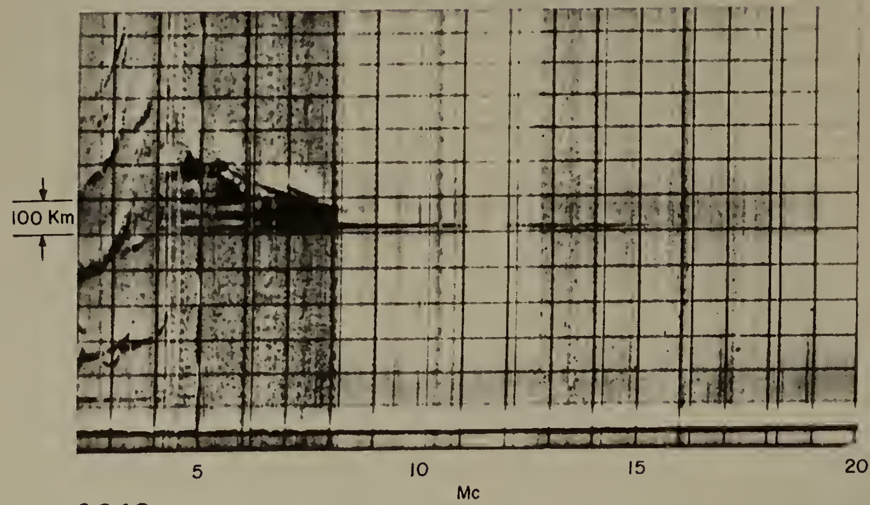


0501



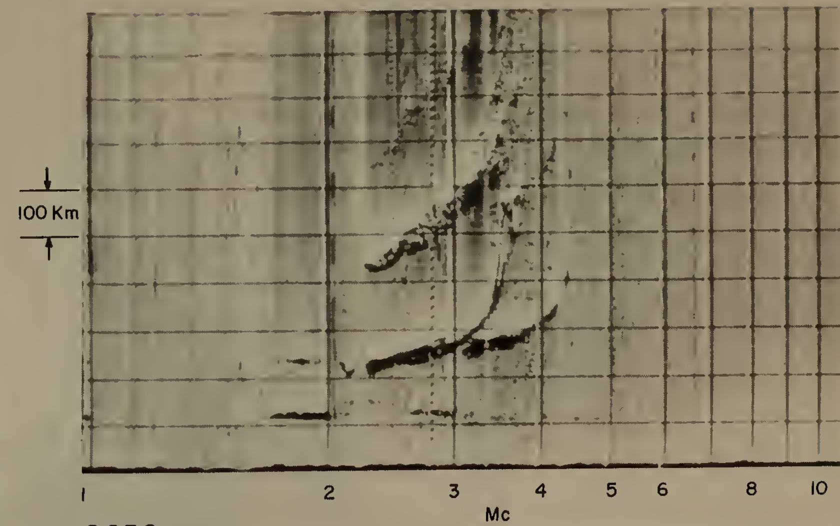
OBLIQUE VERTICAL

JULY 25, 1952



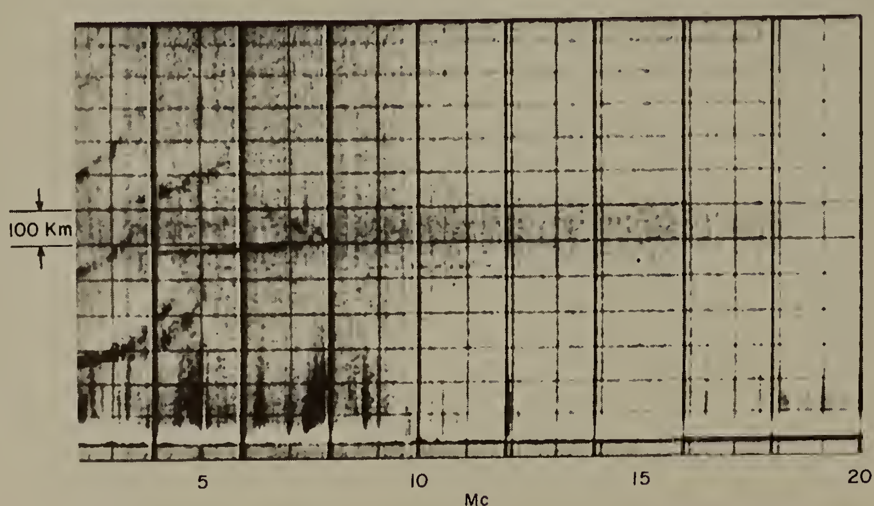
0648

JULY 25, 1952



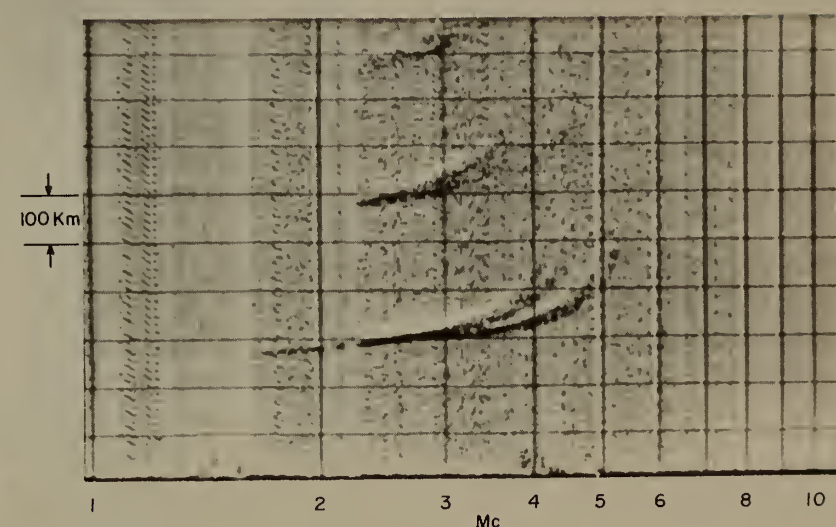
0636

OCTOBER 21, 1952



2110

OCTOBER 21, 1952



2103

Sterling-St. Louis

Ionograms Showing MUF Extensions

September 11, 1952; October 3, September 3, 1951; September 12, July 18, September 26, 1952

Note the following:

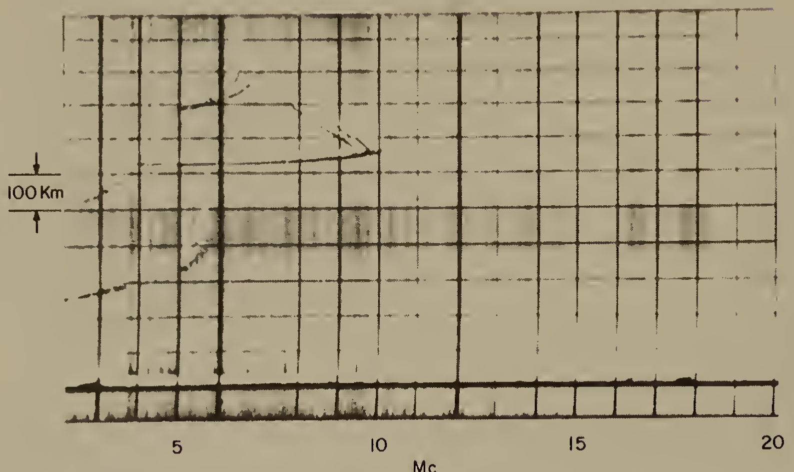
(1) The echoes at frequencies above that which the high-angle and low-angle rays merge. This has been named the MUF extension.

(2) On July 18, September 12 and September 26, it is difficult to separate the 2-hop E echo from the 1-hop F1 echo.

(3) On September 26 there is no extension on the F2 trace, perhaps because of the presence of the underlying F1 layer.

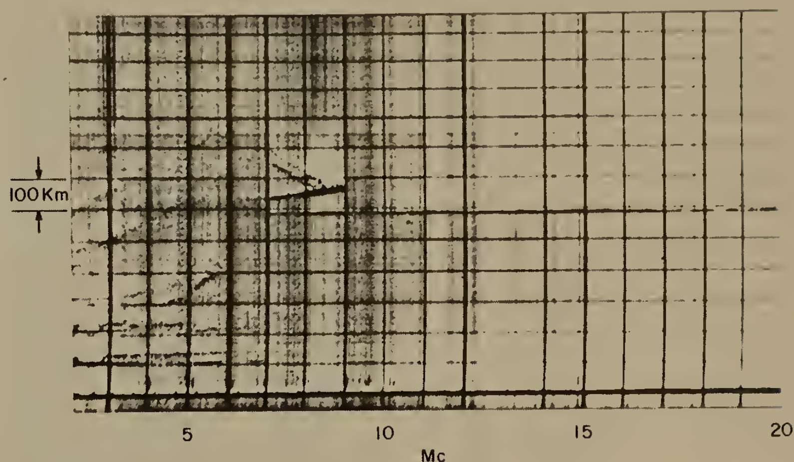
(4) The presence of the MUF extension does not appear to be correlated with the presence of sporadic E.

SEPTEMBER 11, 1952



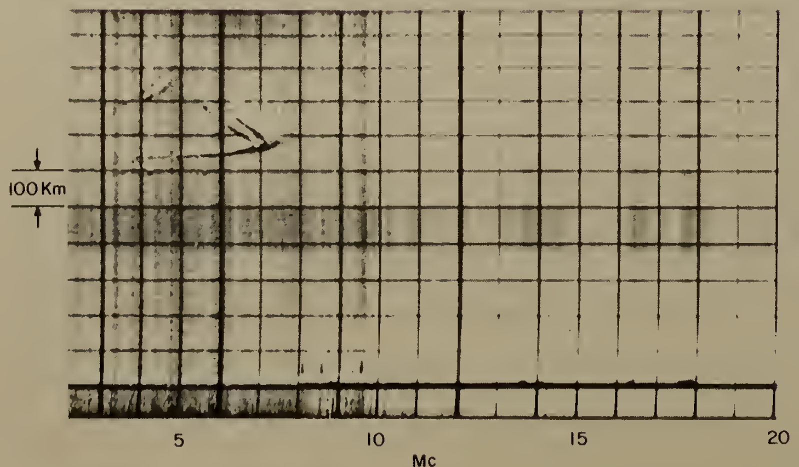
1935

OCTOBER 3, 1951



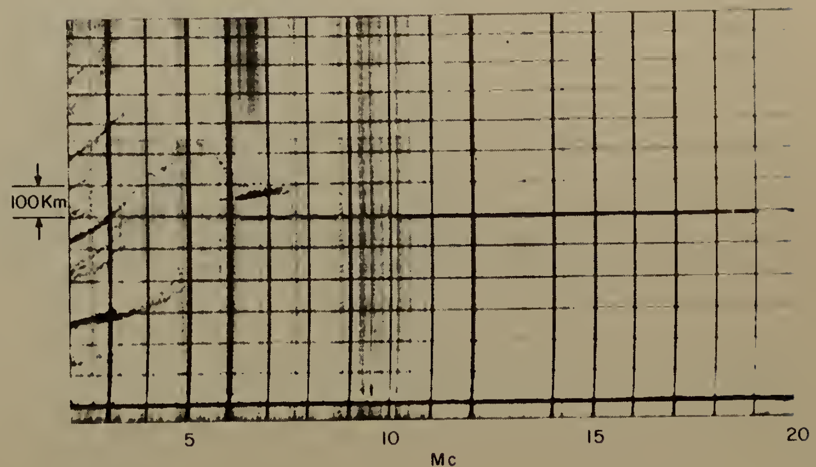
2124

SEPTEMBER 11, 1952



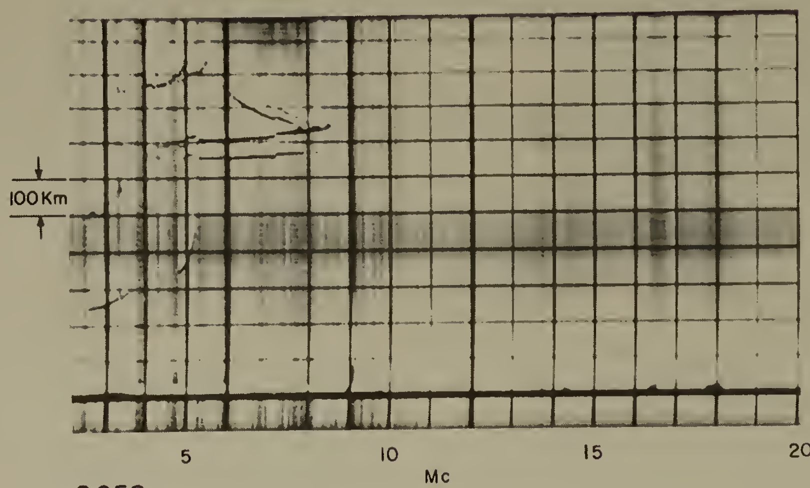
2211

SEPTEMBER 3, 1951



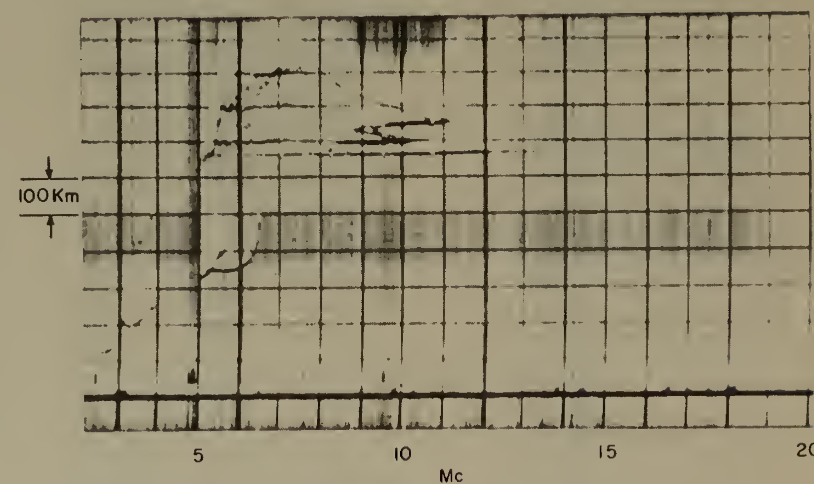
2224

SEPTEMBER 12, 1952



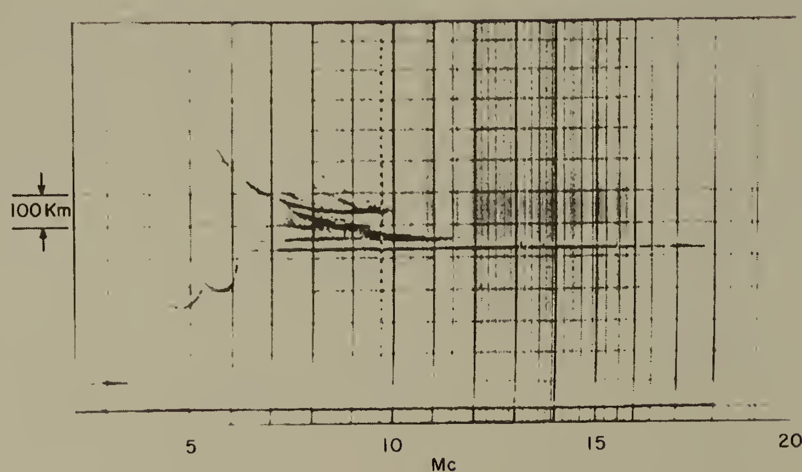
0652

SEPTEMBER 12, 1952



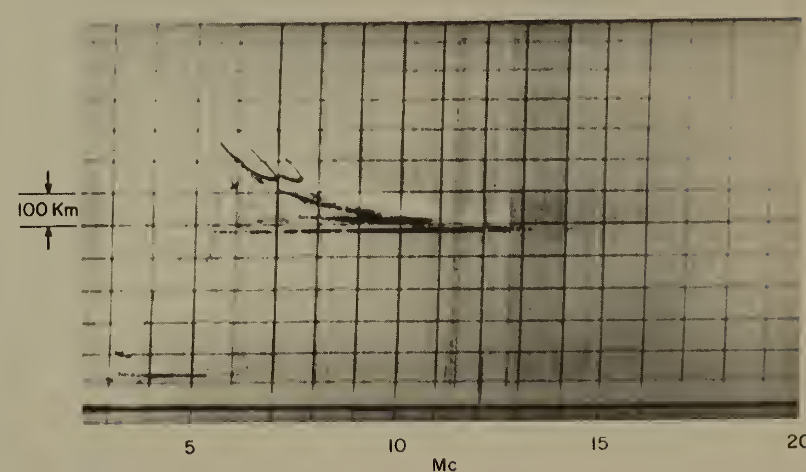
0952

JULY 18, 1952



1014

SEPTEMBER 26, 1952



1132

Sterling-St. Louis

Ionograms Showing Effects of Equipment Sensitivity

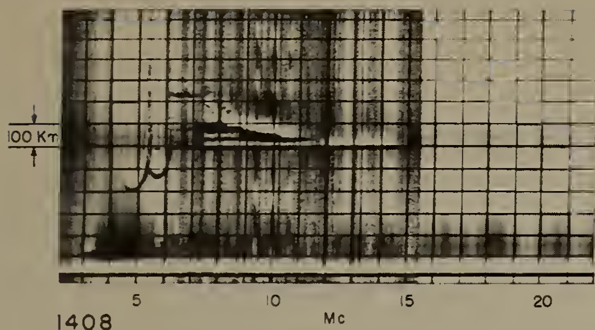
May 28, July 18, September 5, 1952

(1) Note in the May 28 records the relative strength of the high-angle F1 ray.

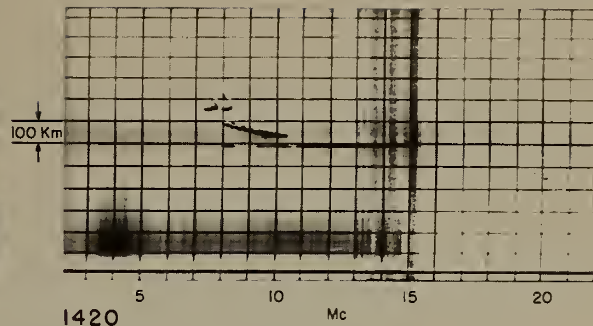
(2) In the ionograms for July 18 the number of multiples is markedly reduced as the gain is reduced.

(3) In the September 5 records the disappearance of the Es trace is to be noted.

MAY 28, 1952

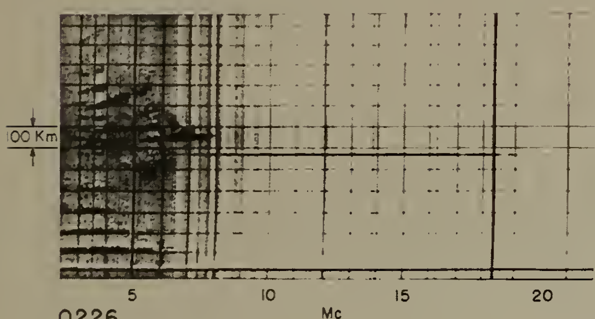


1408

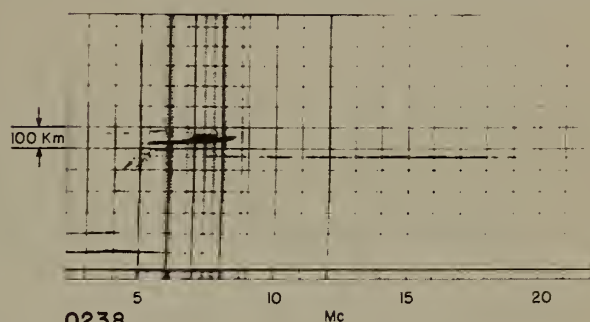


1420

JULY 18, 1952

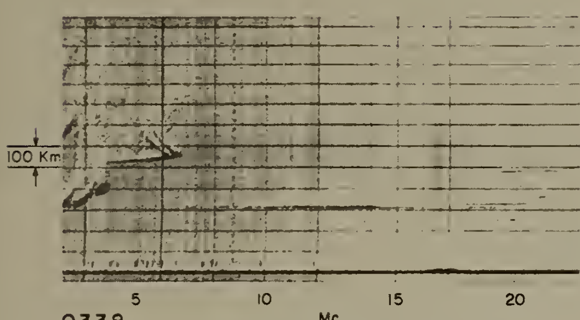


0226



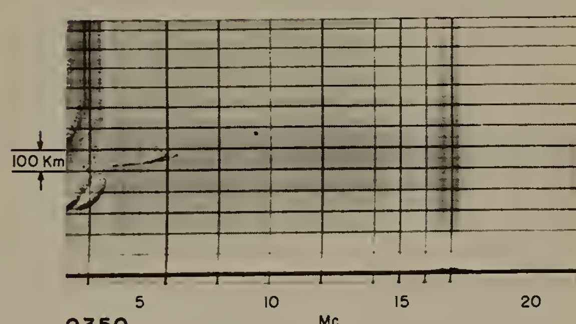
0238

SEPTEMBER 5, 1952



0338

HIGH GAIN



0350

LOW GAIN

Sterling-St. Louis

Ionograms Showing Relative Importance of High-Angle Ray

May 14, 1952

The one-hop low-angle ray is cut off by sporadic E which is evident on the oblique-incidence record (1945) but not on the vertical-incidence ionogram (1942). The high-angle ray may, therefore, be relatively important (note the presence of M and N-type echoes).

May 15, 1952

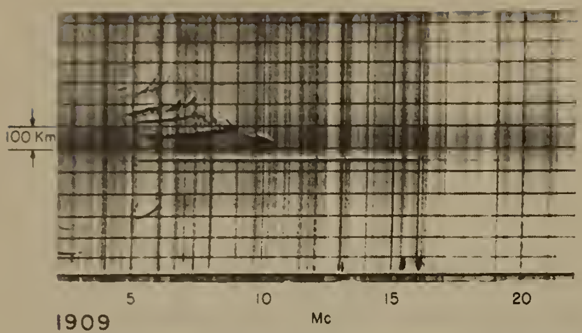
Here again the low-angle ray has been cut off by intense sporadic E.

October 3, November 18, December 2, 1952

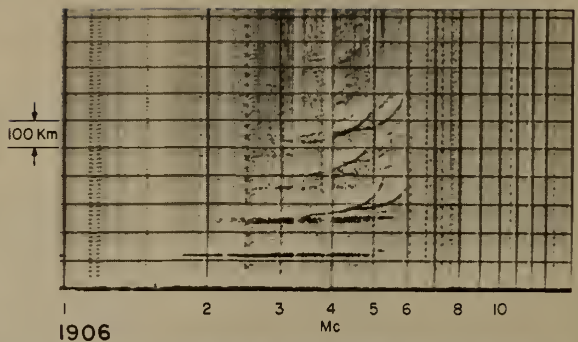
The high-angle ray here is relatively unimportant. This is especially typical of winter day conditions.

February 13, July 17, August 28, September 11, 1952

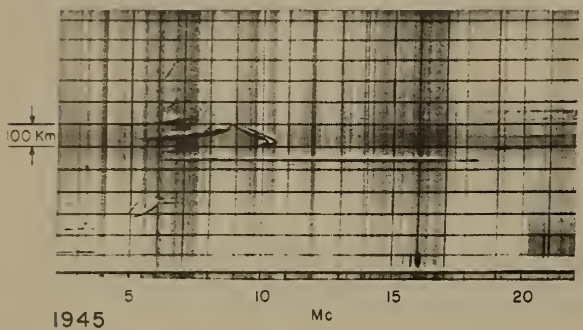
An example showing the relatively rare high-angle E-layer ray.



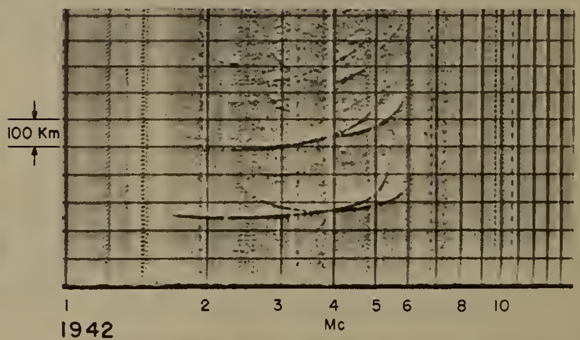
1909



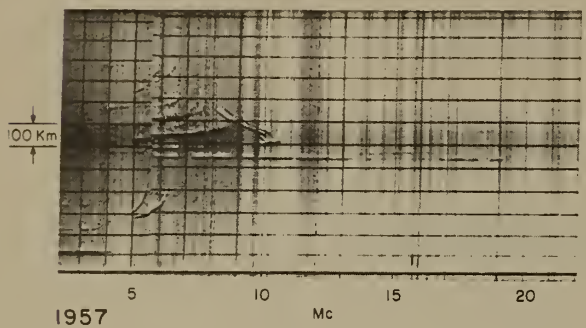
1906



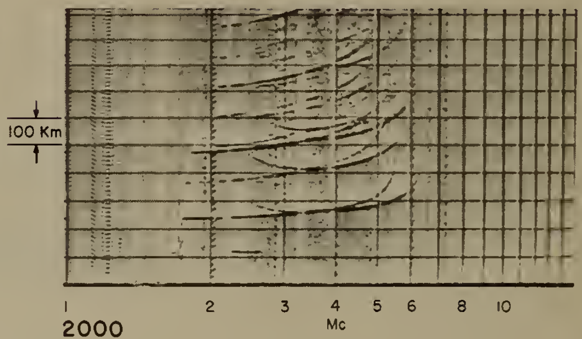
1945



1942

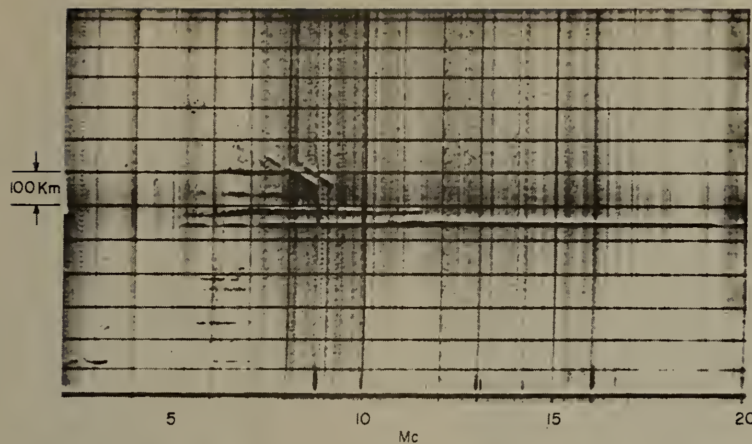


1957

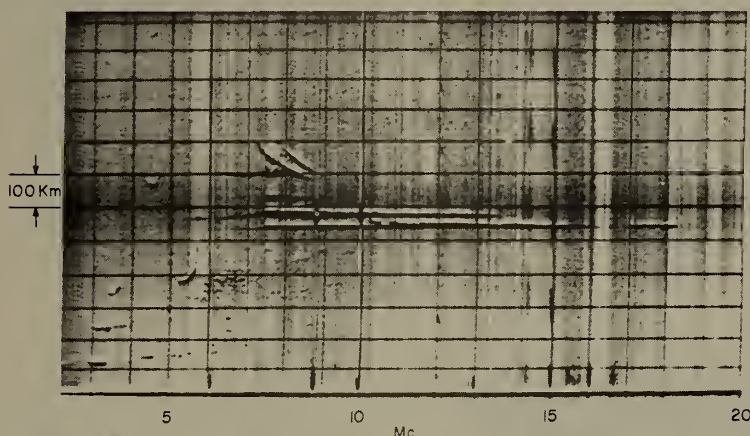


2000

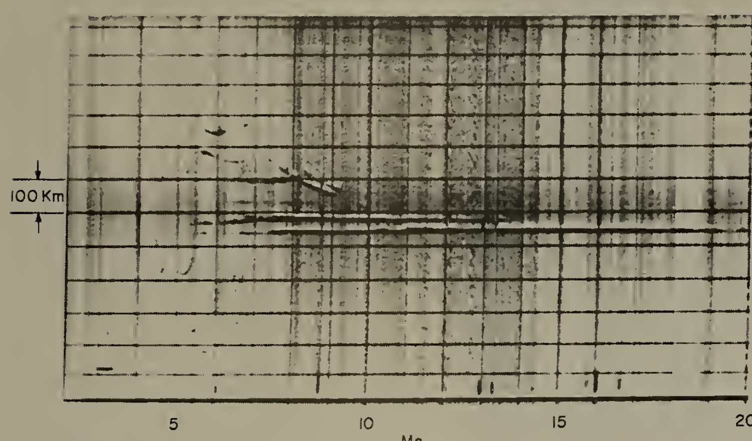
MAY 15, 1952



0833

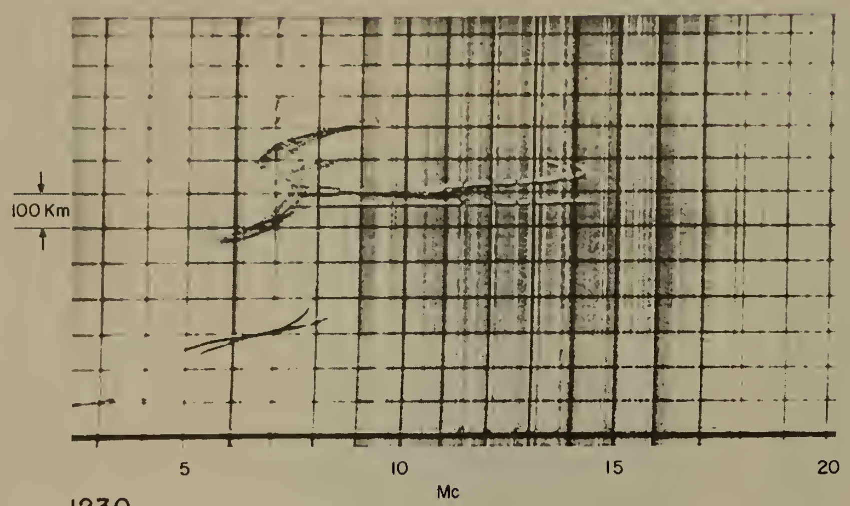


0845



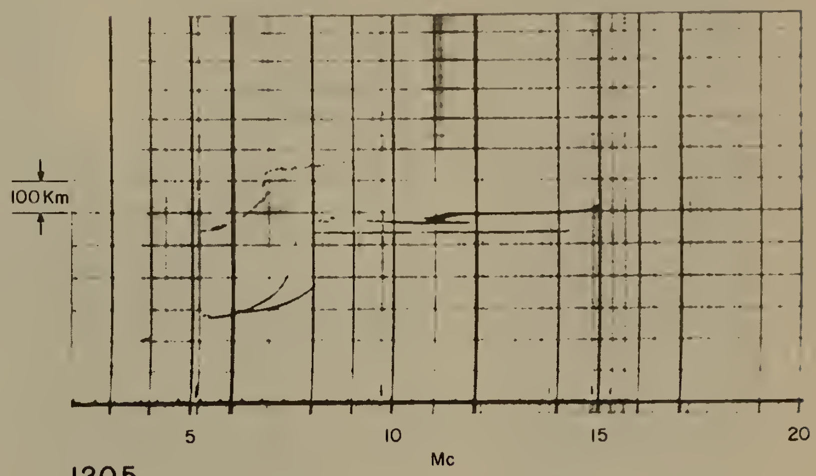
0857

OCTOBER 3, 1951



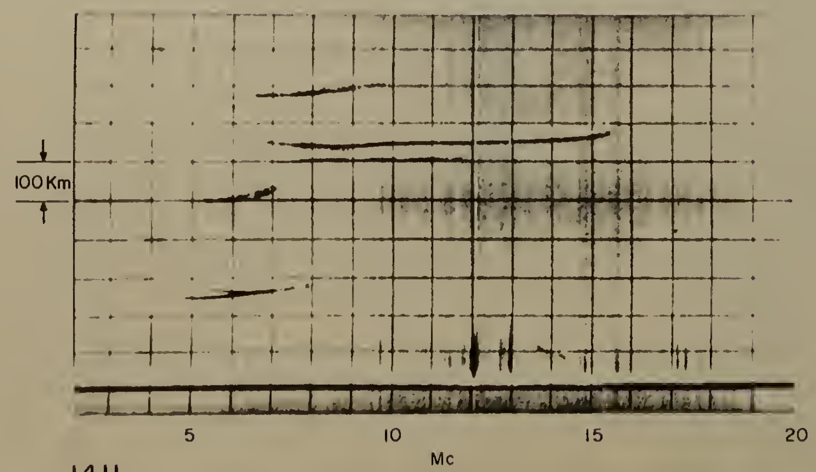
1230

OCTOBER 3, 1951



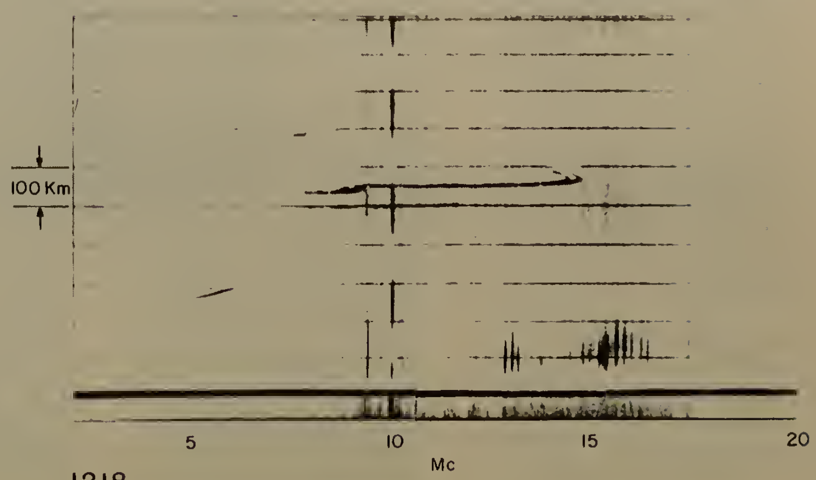
1205

NOVEMBER 18, 1952



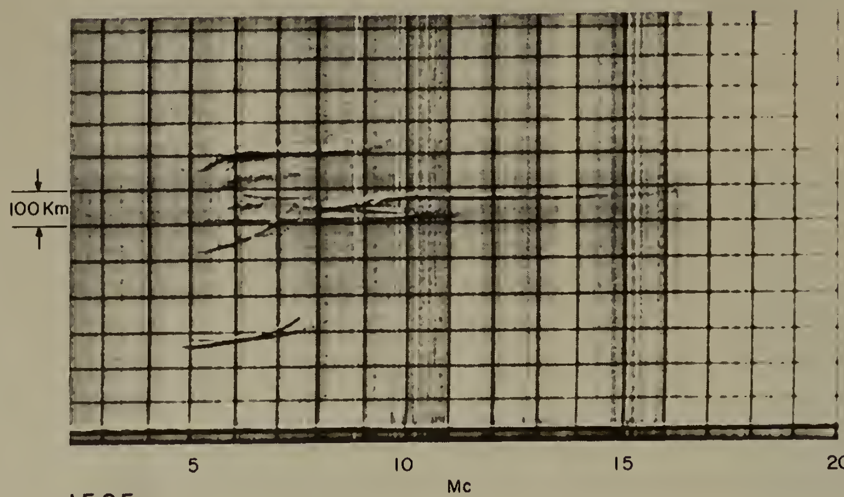
1411

DECEMBER 2, 1952

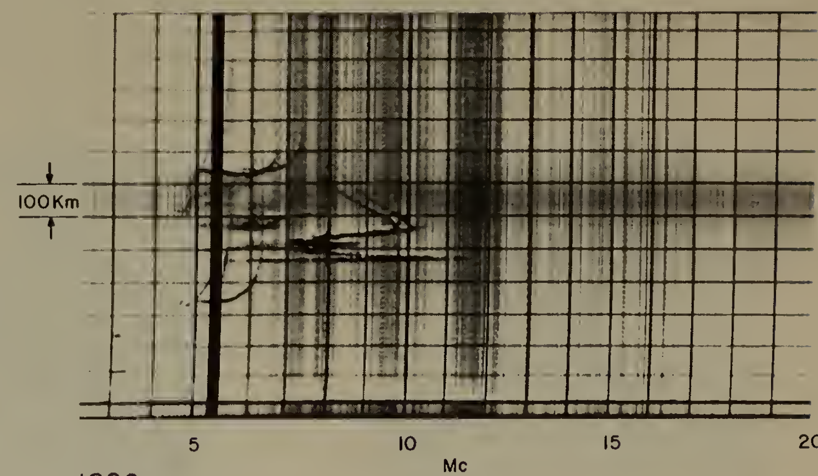


1218

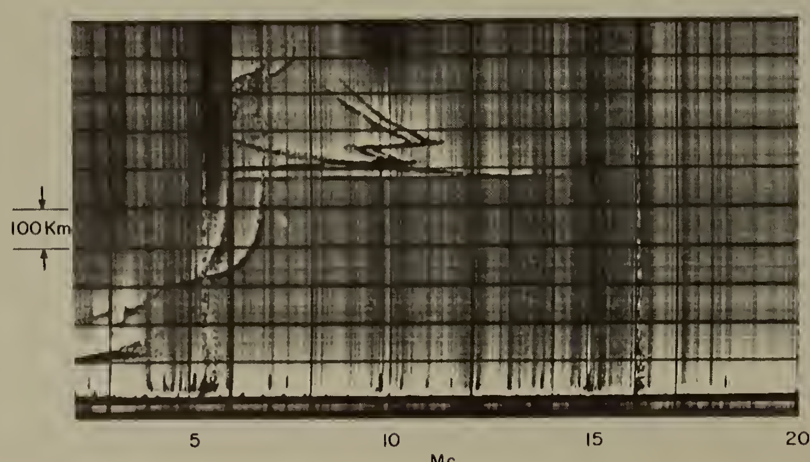
FEBRUARY 13, 1952



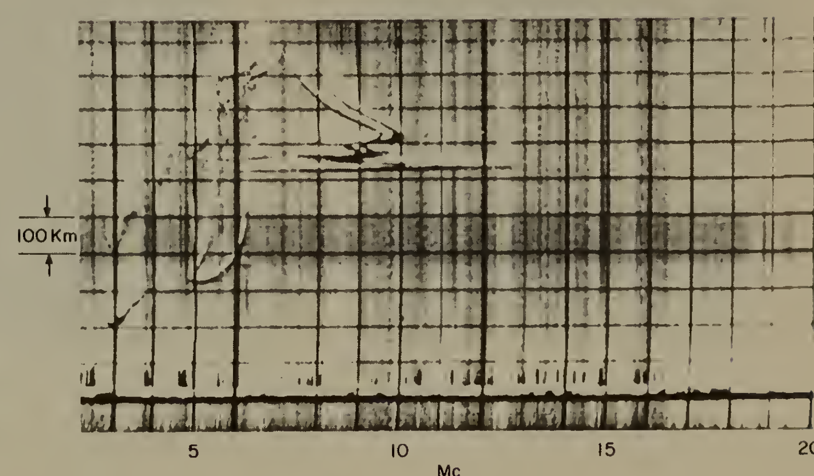
JULY 17, 1952



AUGUST 28, 1952



SEPTEMBER 11, 1952



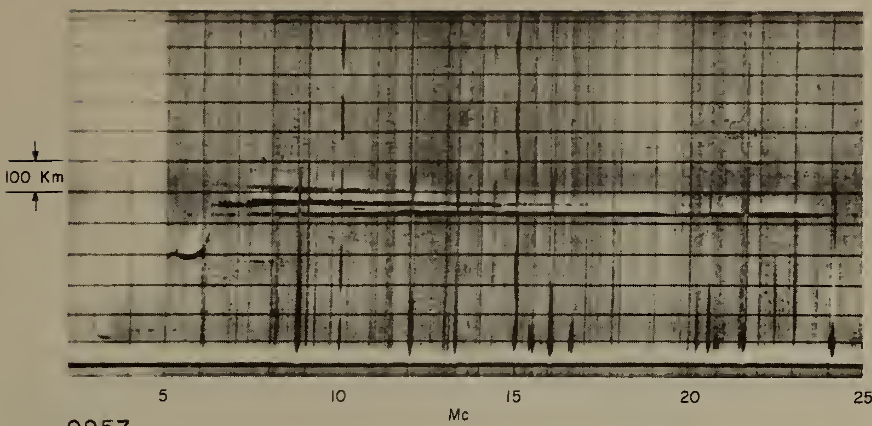
Sterling-St. Louis

Ionograms Showing Sporadic E Reflections

May 15, July 17, 1952

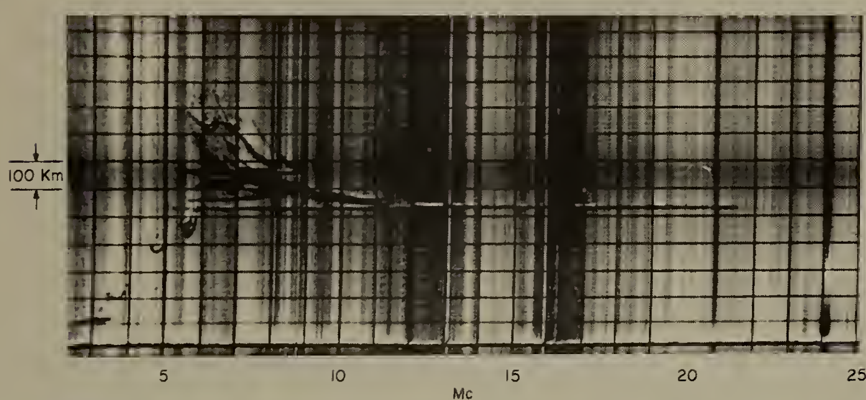
On both records Es extends out past 20 Mc and the record for May 15 shows blanketing of the F-layer echoes. The record for July 17 gives an example of complex echo structure.

MAY 15, 1952



0957

JULY 17, 1952



1614

Sterling-St. Louis

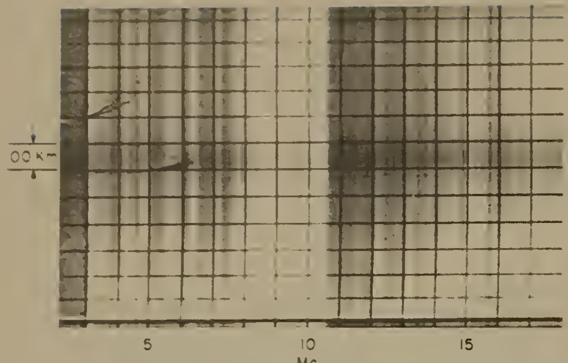
Sequences Showing Moving Irregularities

April 30, 1952

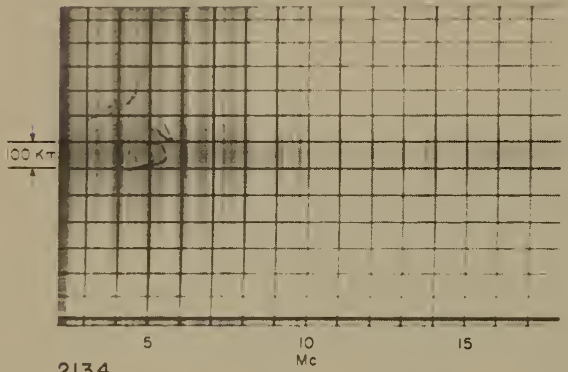
Moving irregularity seen on oblique-incidence ionograms not apparent on the vertical-incidence records.

May 28, 1952

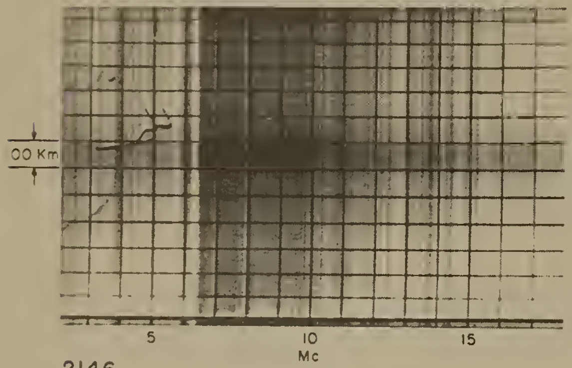
Apparent downward motion of irregularity indicated.



2122

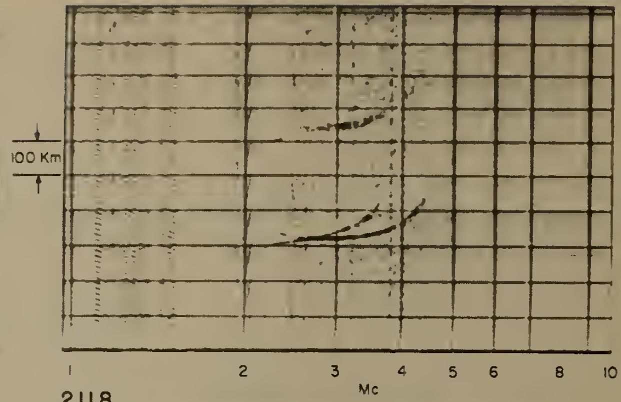


2134

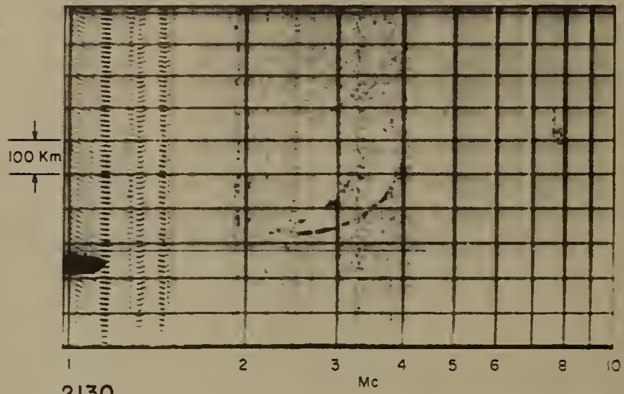


2146

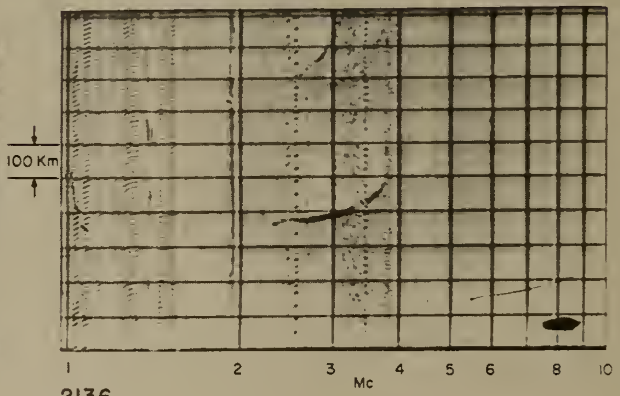
OBLIQUE



2118



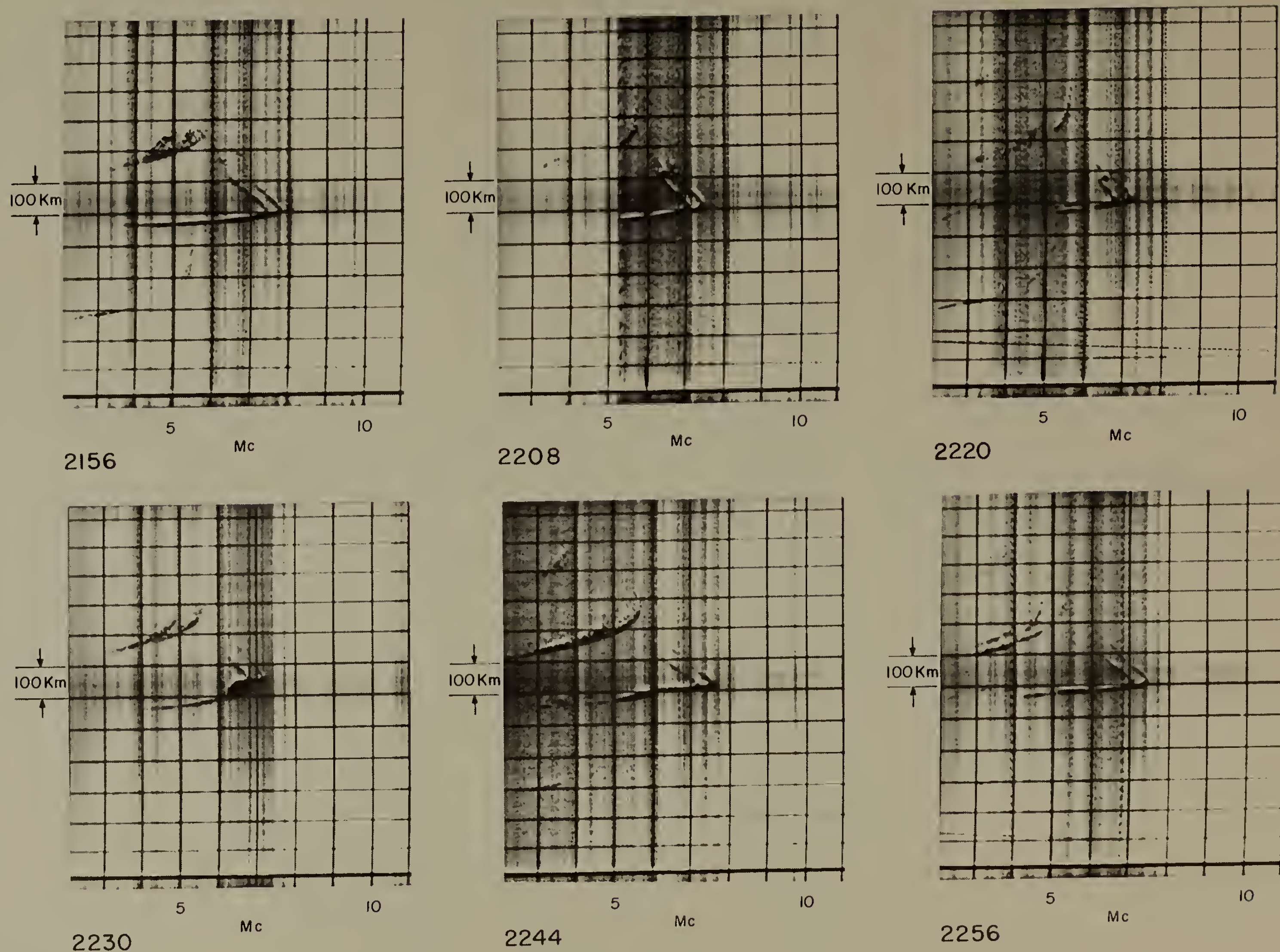
2130



2136

VERTICAL

MAY 28, 1952



MOVING IRREGULARITIES

Sterling-St. Louis

Ionograms Showing Unusual and Complex Traces

February 6, March 19, December 3, 1952

Apparent stratifications and complex traces.

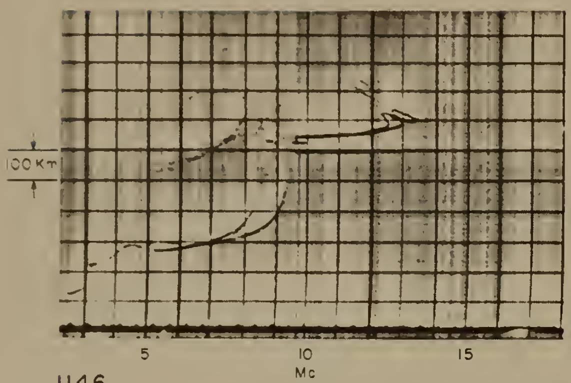
May 22, 1952

Here the complexities show up in the 2-hop echo trace.

August 8, May 8, 1952

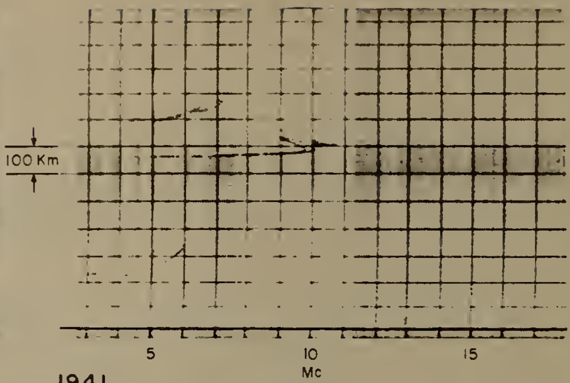
The Pedersen ray ordinary and extraordinary traces are differently shaped.

FEBRUARY 6, 1952



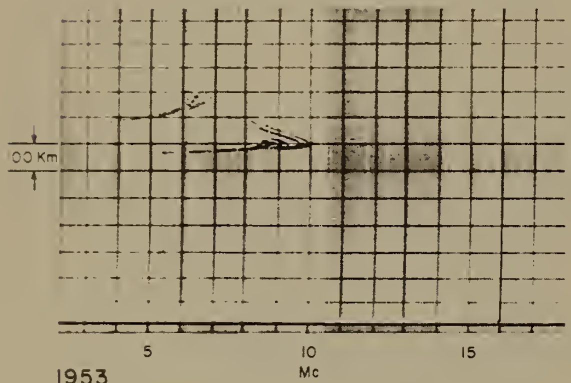
1146

MARCH 19, 1952



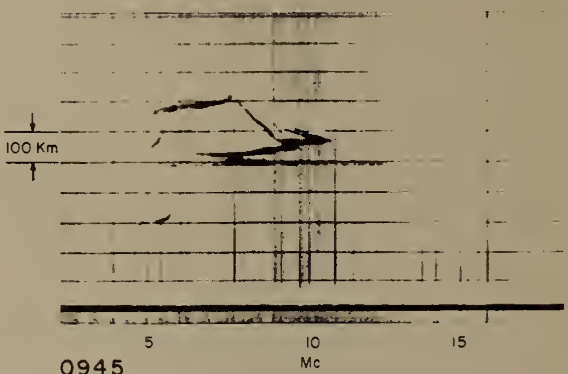
1941

MARCH 19, 1952



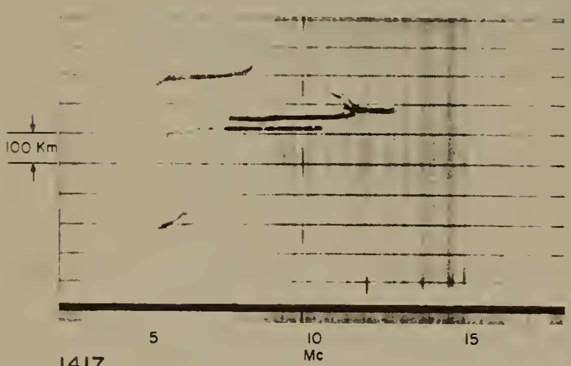
1953

DECEMBER 3, 1952

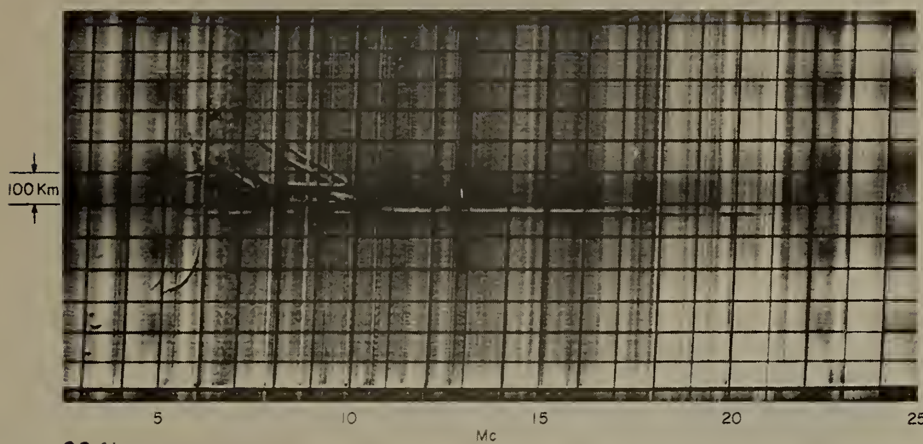


0945

DECEMBER 3, 1952



1417



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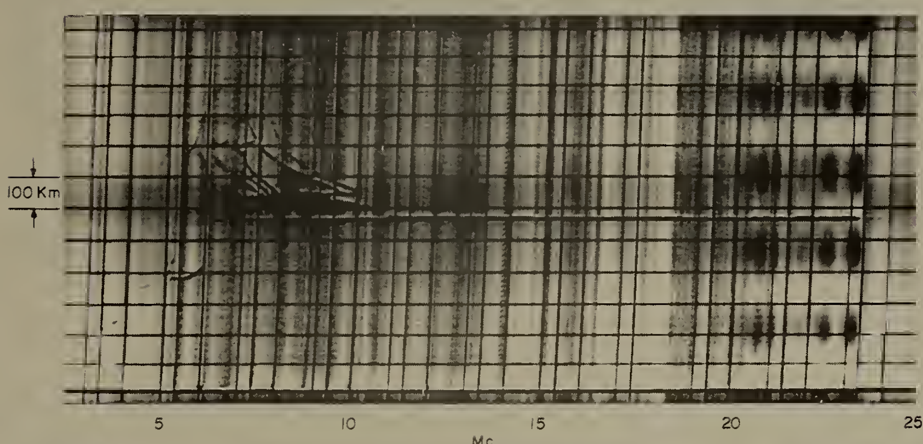

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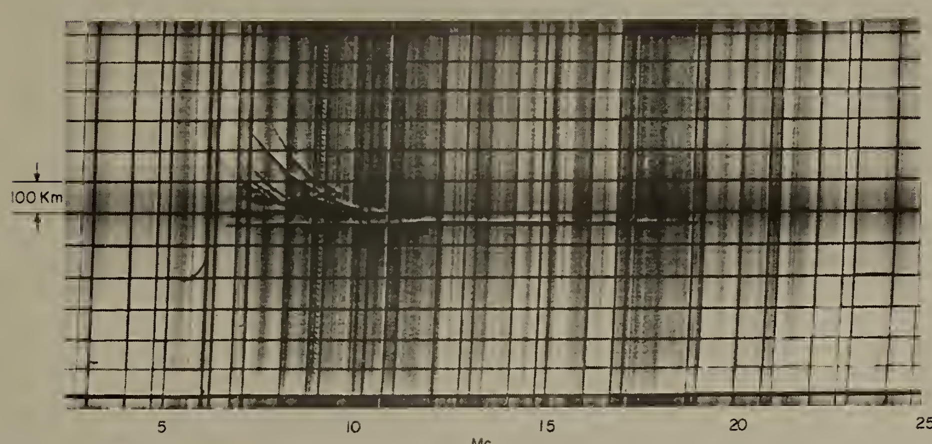
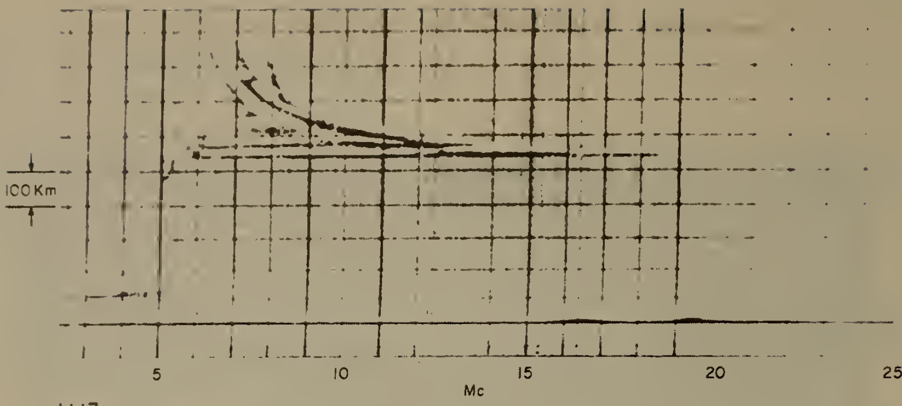


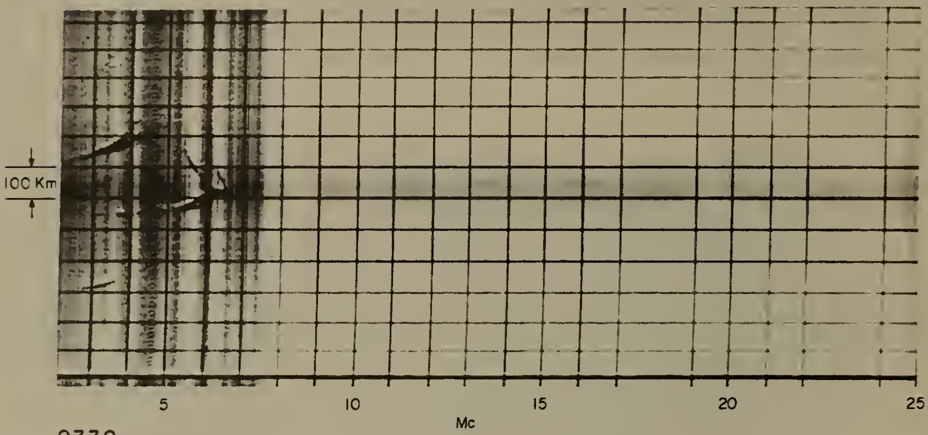
0905

AUGUST 8, 1951



1113

MAY 8, 1952



2332

II. Sterling-Boulder - 2370 km
(Routine)

Sterling-Boulder
(Routine)

Sequences Showing Diurnal Variation

Winter Day
February 3-4, 1954

$\Sigma K_p = 18-$

Winter Day
February 10-11, 1954

$\Sigma K_p = 18+$

Equinoctial Day
March 31-April 1, 1954

$\Sigma K_p = 15-$

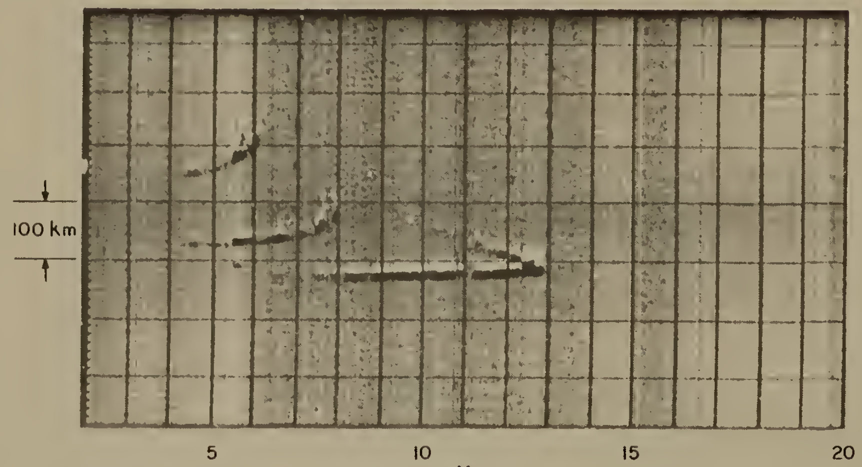
Summer Day
May 11-12, 1954

$\Sigma K_p = 15-$

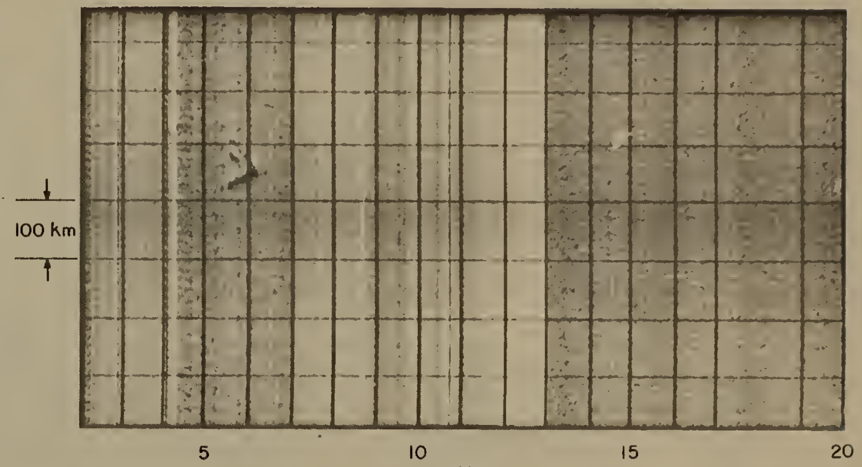
Summer Day
August 4-5, 1954

$\Sigma K_p = 10$

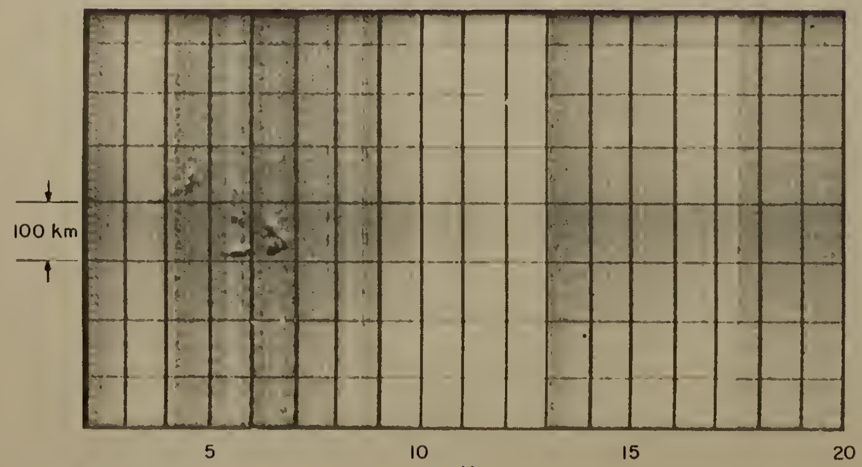
FEBRUARY 3-4, 1954



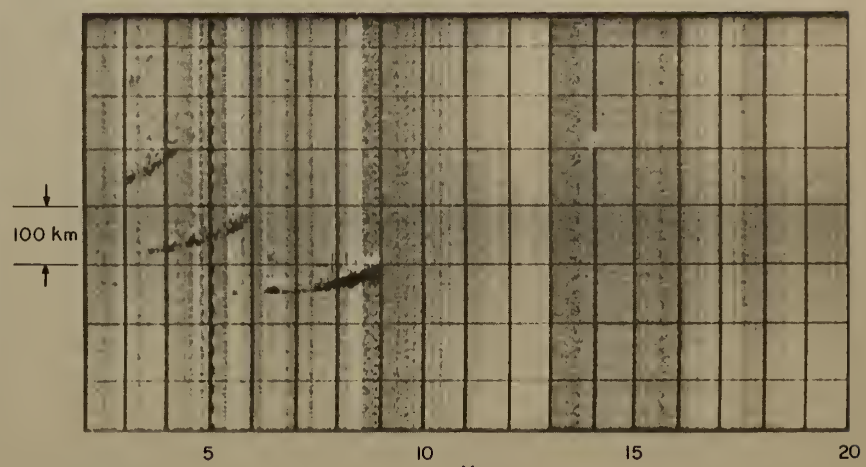
1815



2103

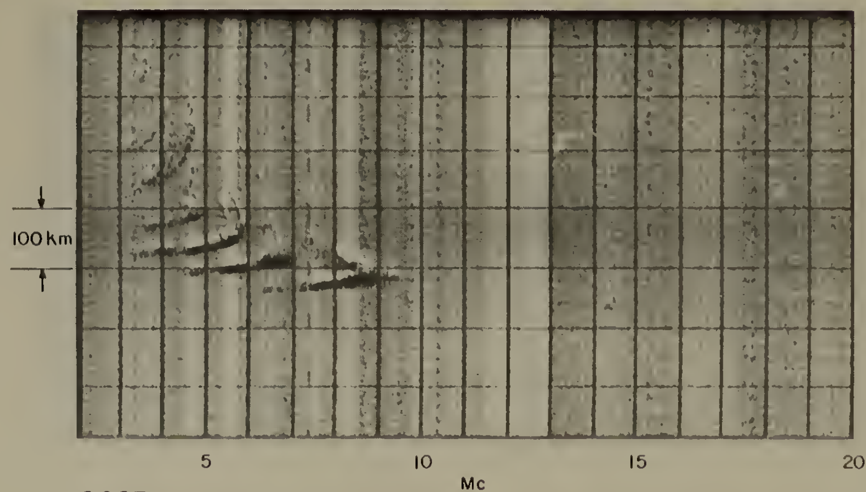


0015

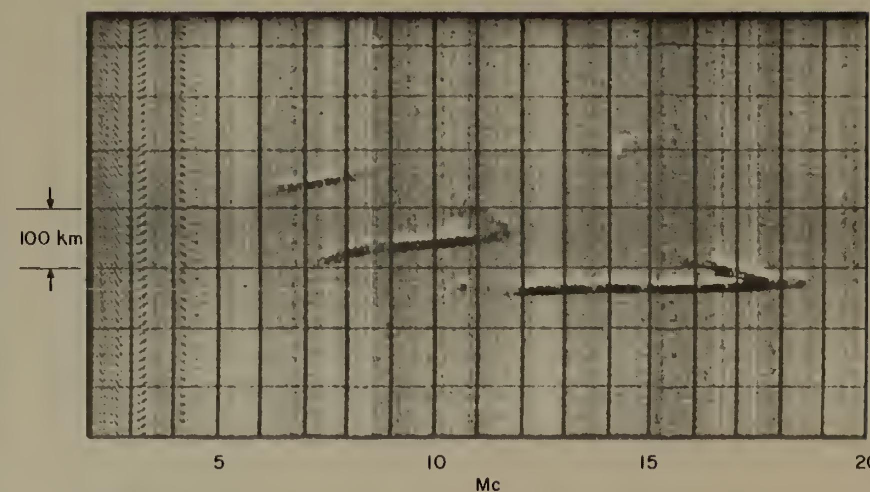


0303

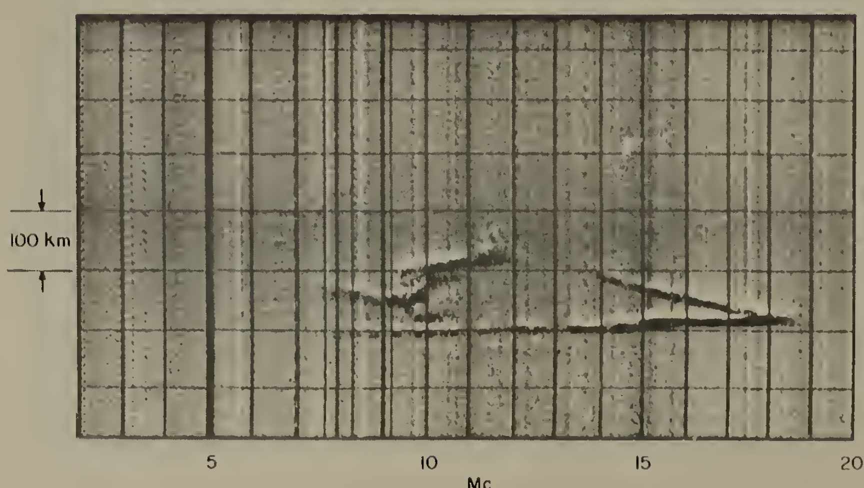
FEBRUARY 4, 1954



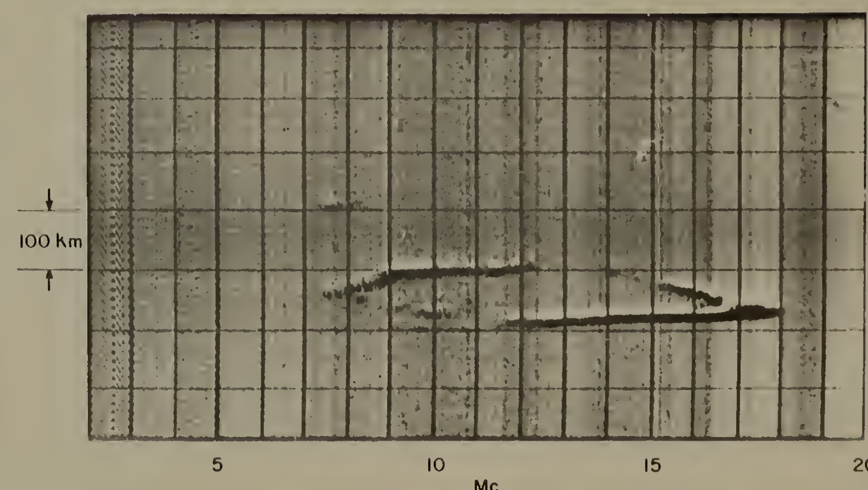
0603



0903

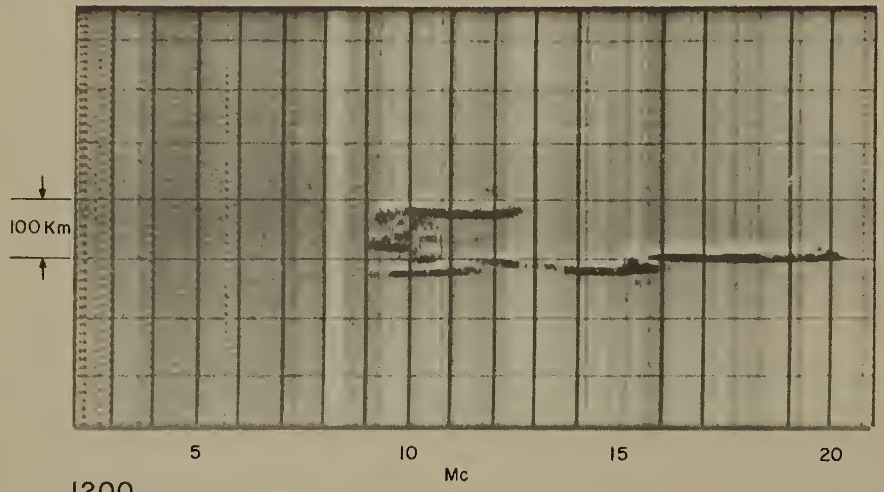


1203

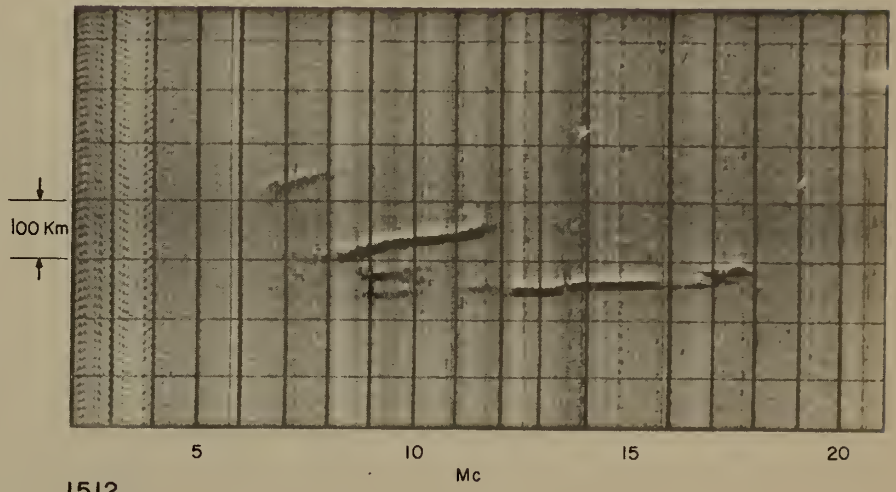


1503

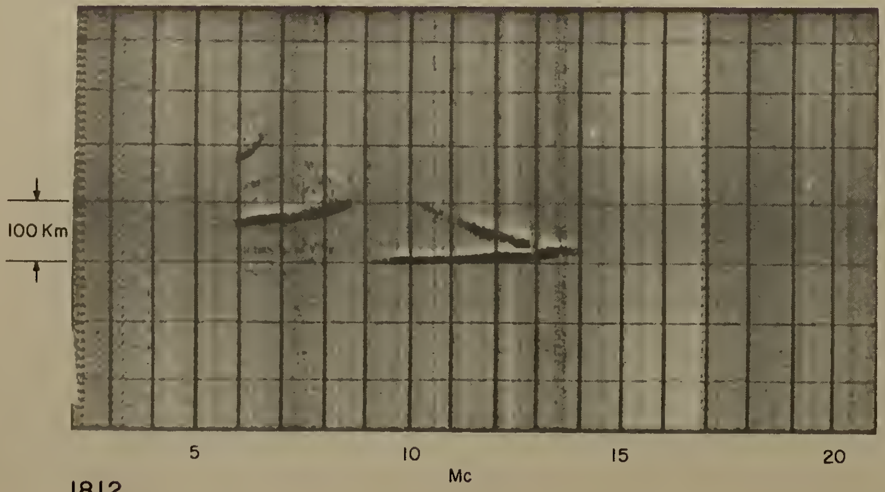
FEBRUARY 10, 1954



1200



1512



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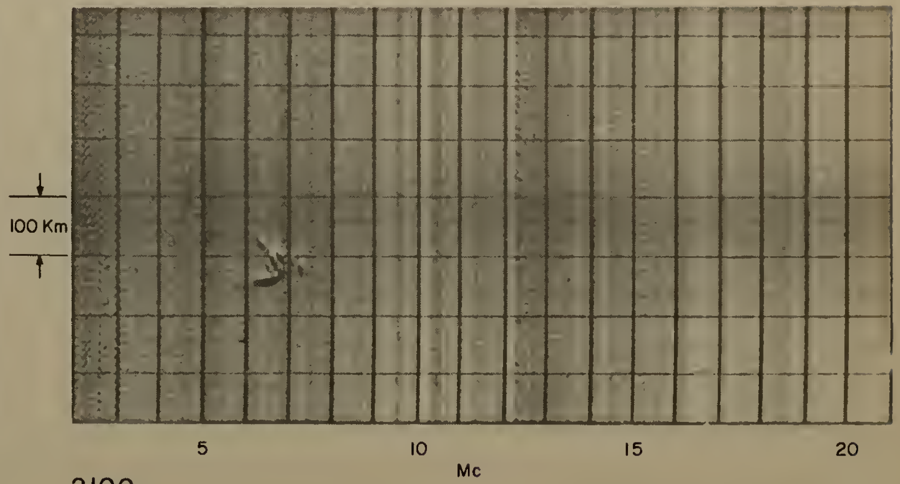
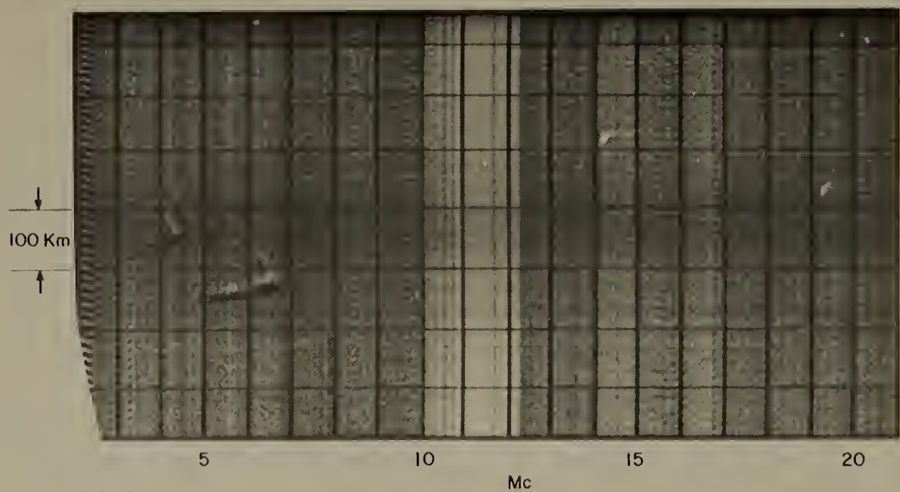
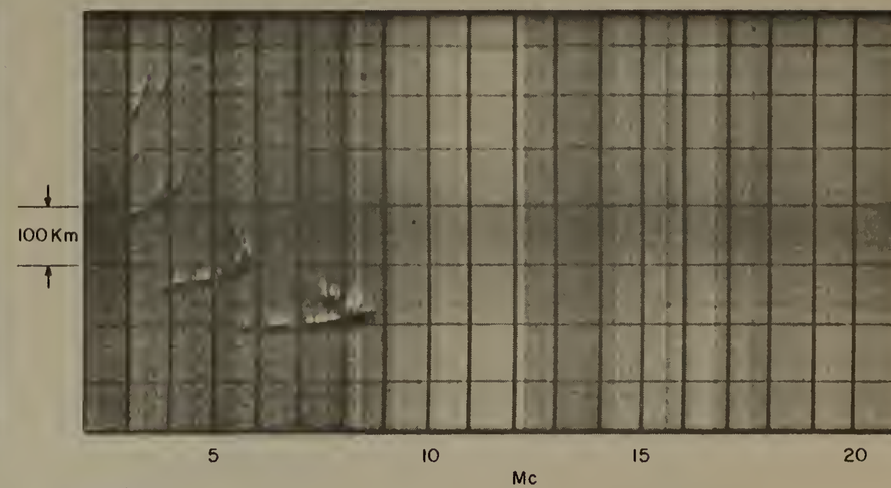


2100

FEBRUARY 11, 1954



0012



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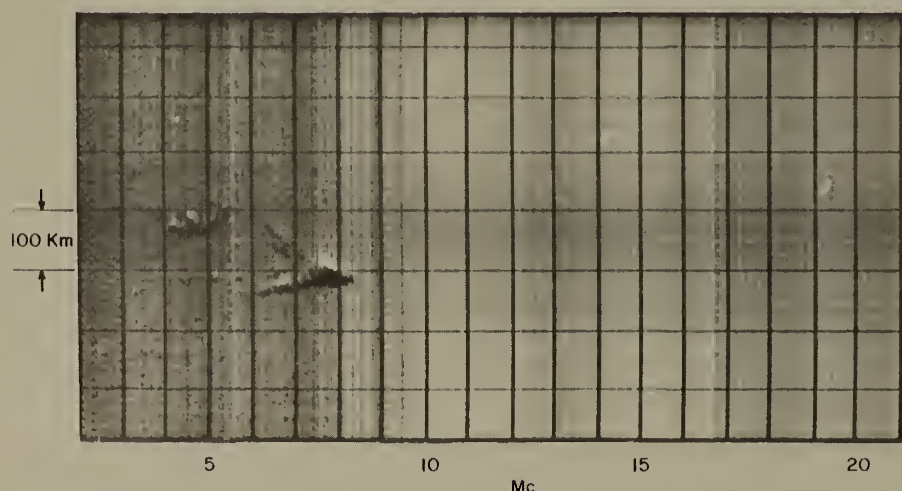
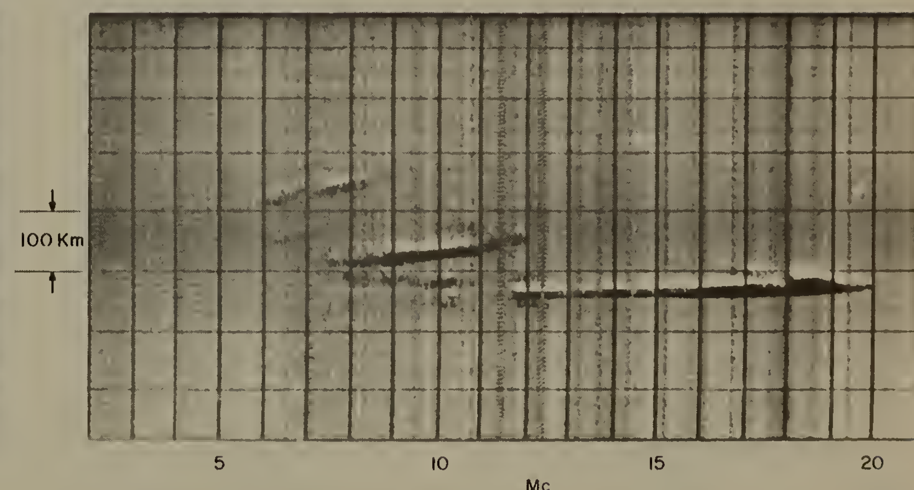


0600



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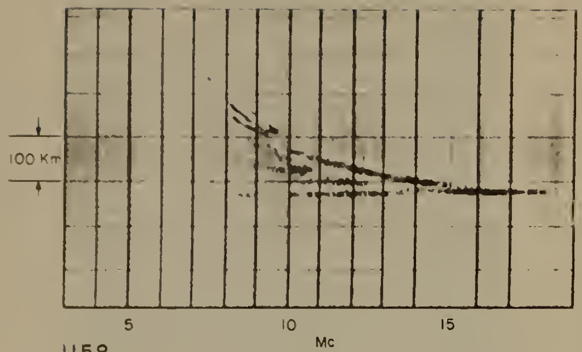
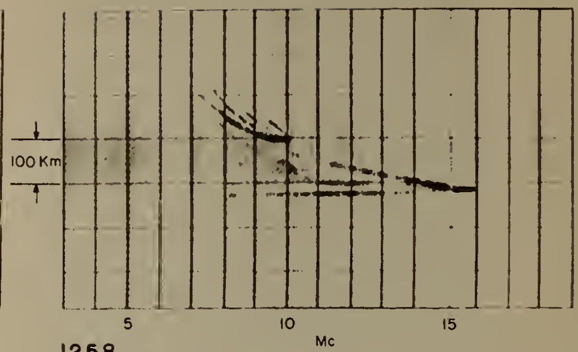
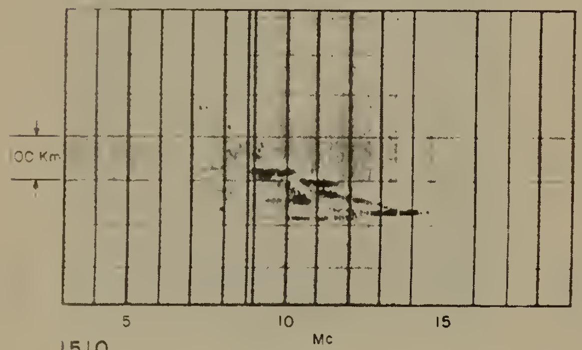


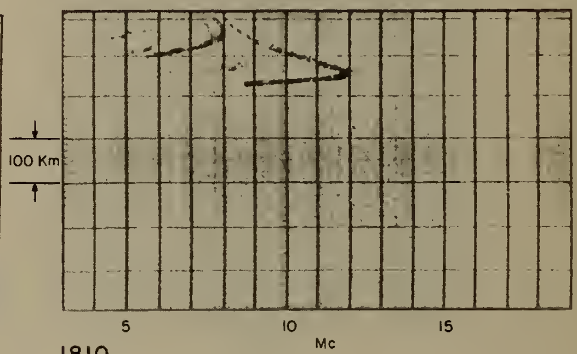
1158



1258



1510



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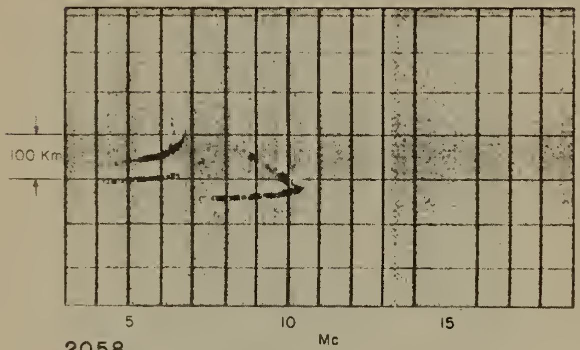

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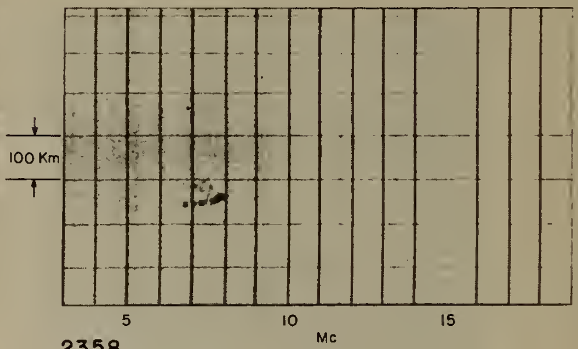

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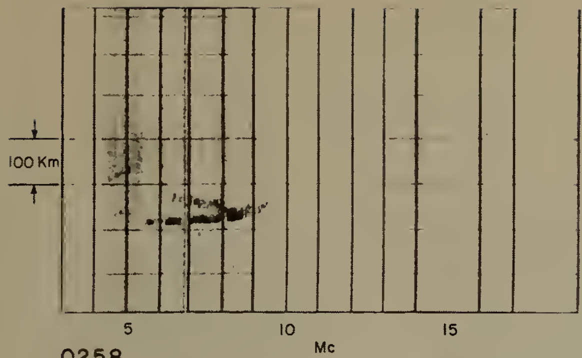
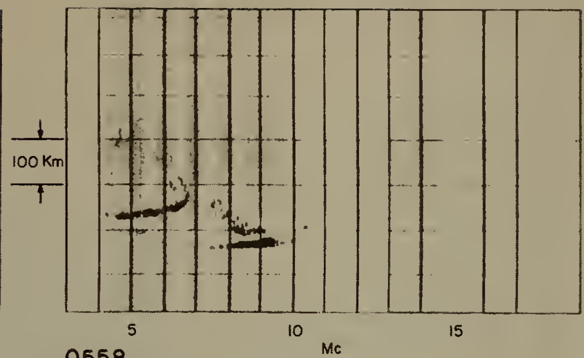


0258



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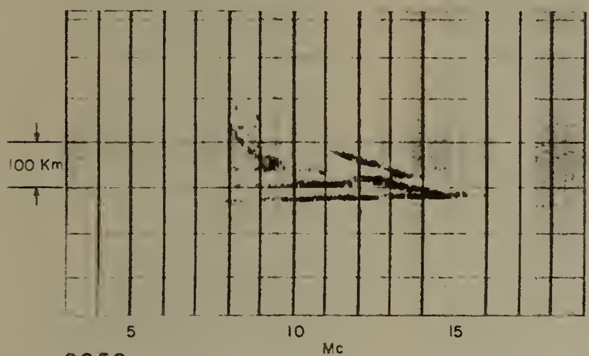

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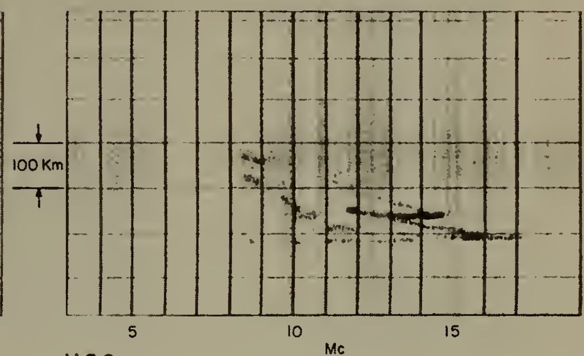
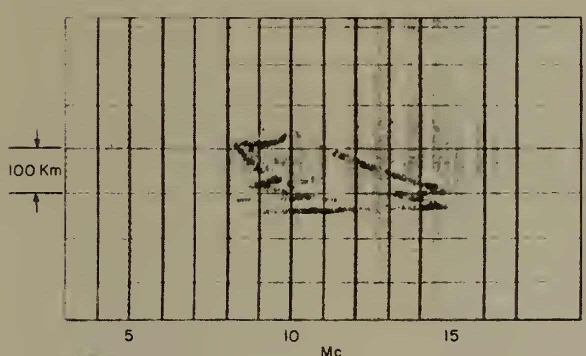
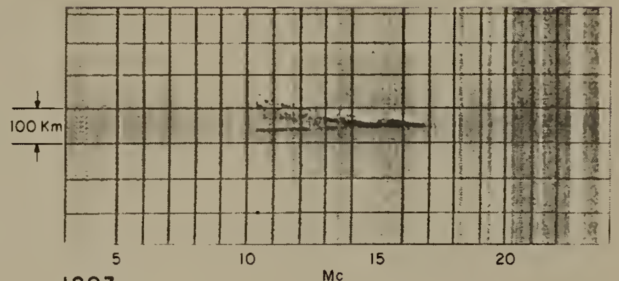


1158



1458

MAY 11, 1954



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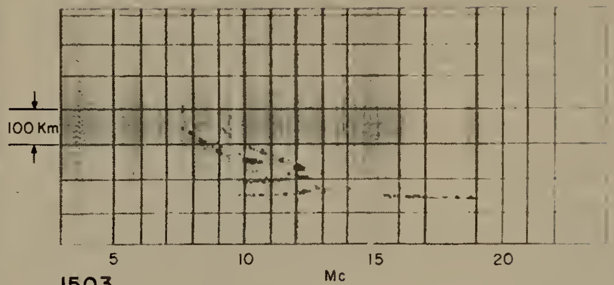

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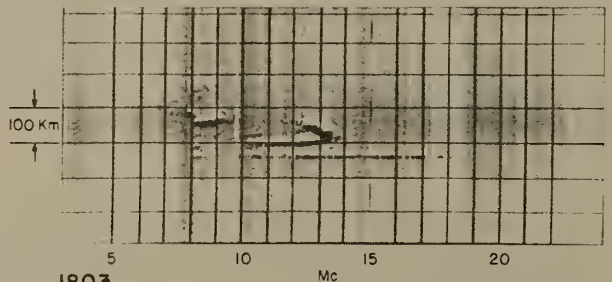
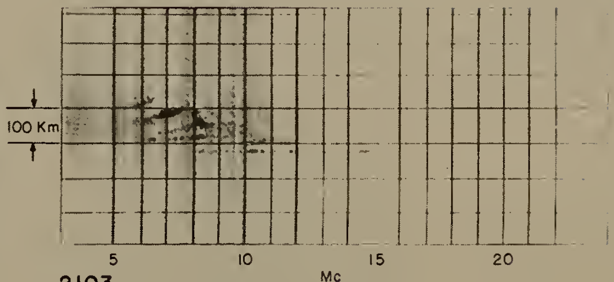
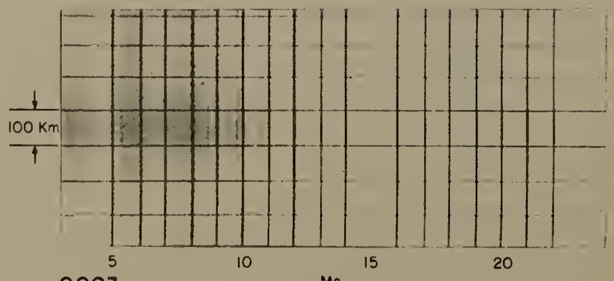


1803

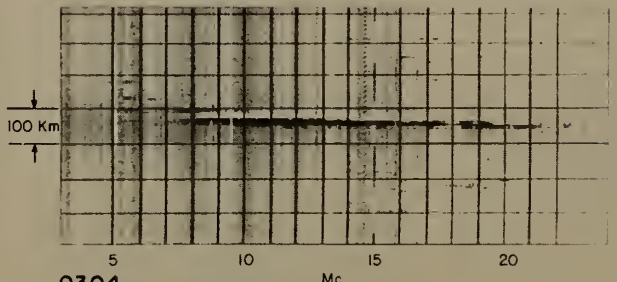


2103

MAY 12, 1954

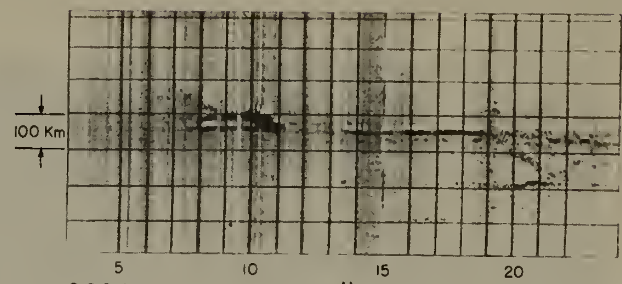


0003



0304

MAY 12, 1954



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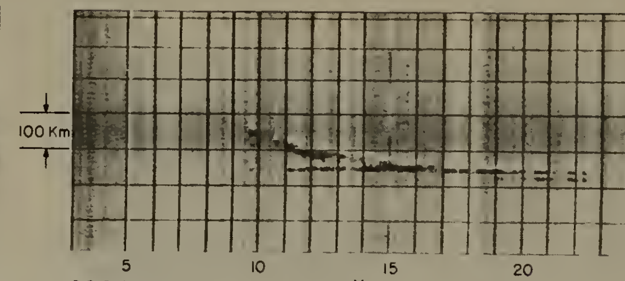
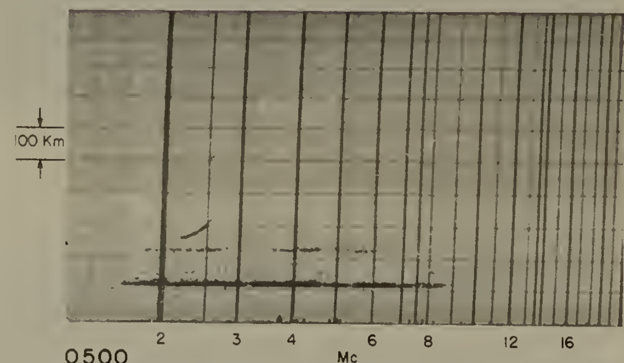


0904

MIDPOINT VERTICAL INCIDENCE



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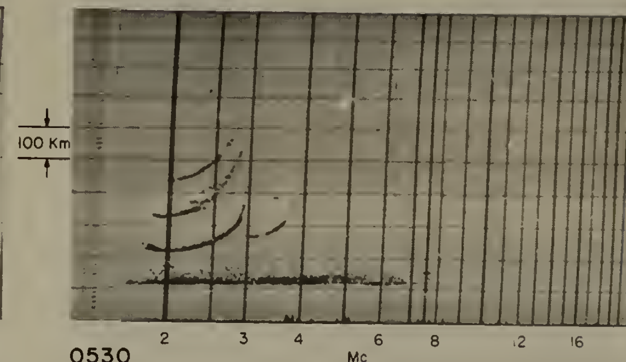

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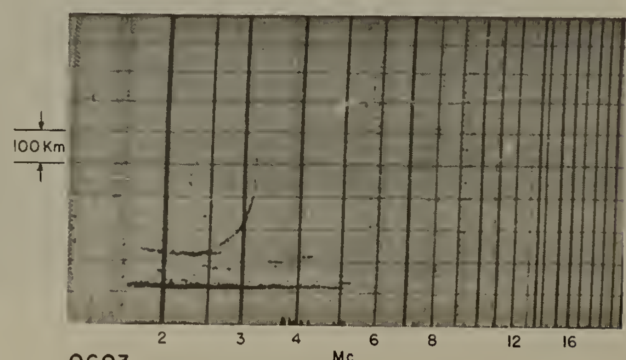
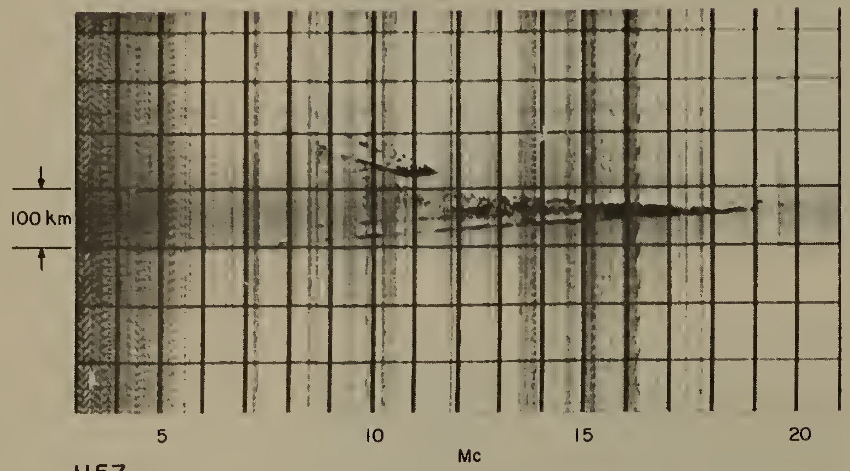
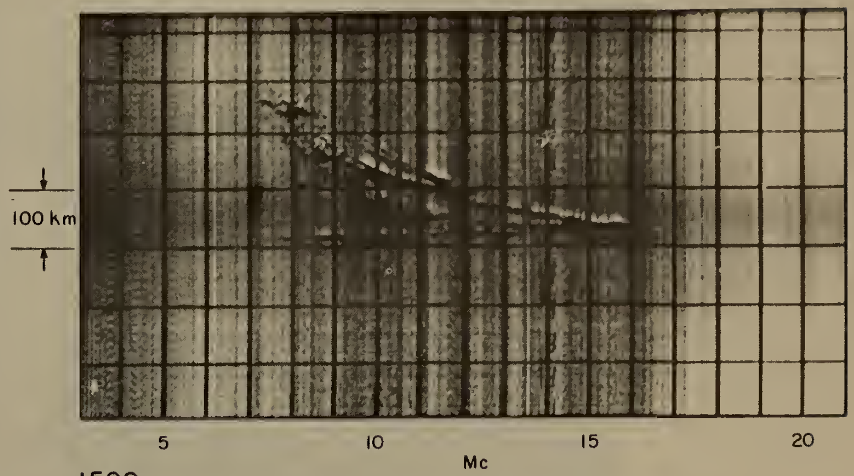


0603

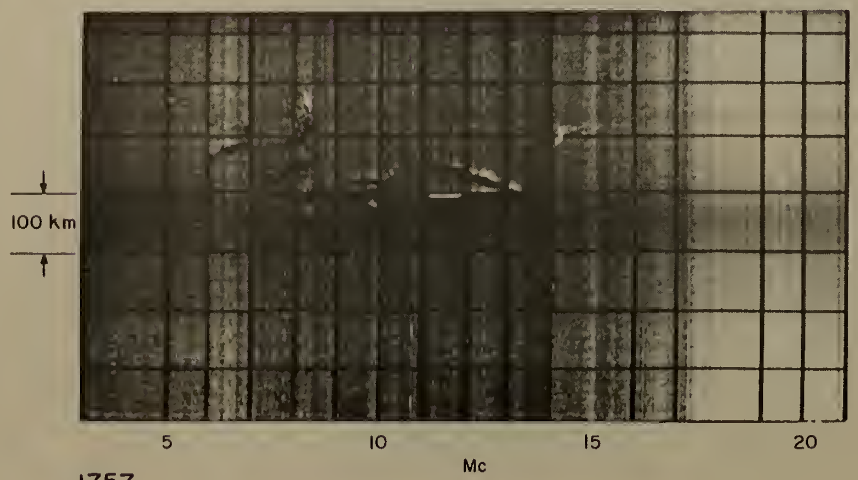
AUGUST 4, 1954



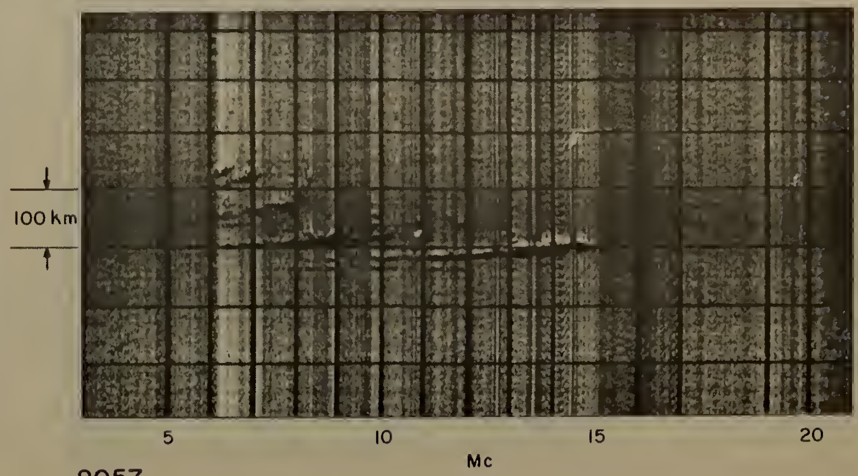
1157



1509

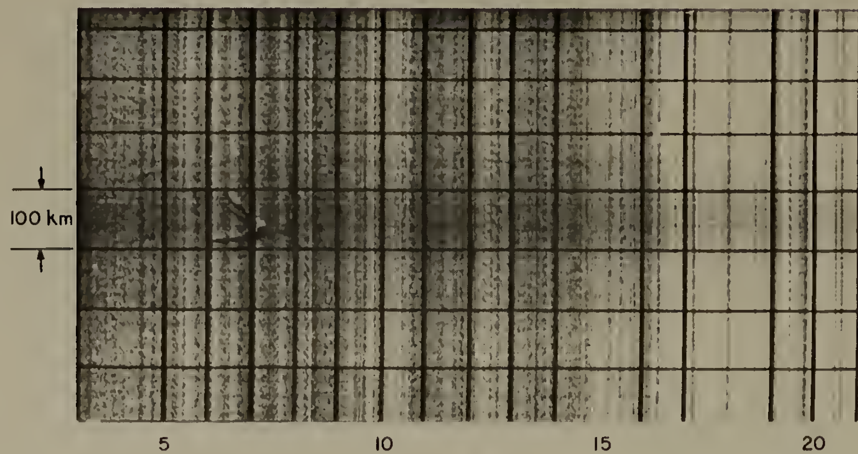


1757

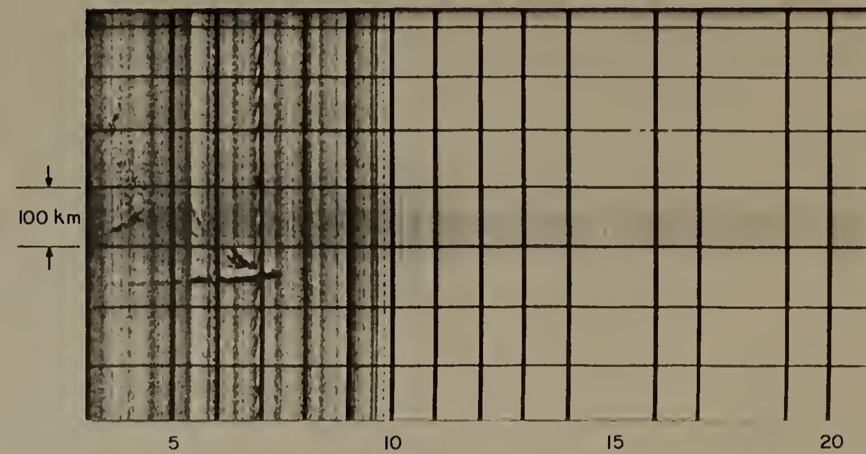


2057

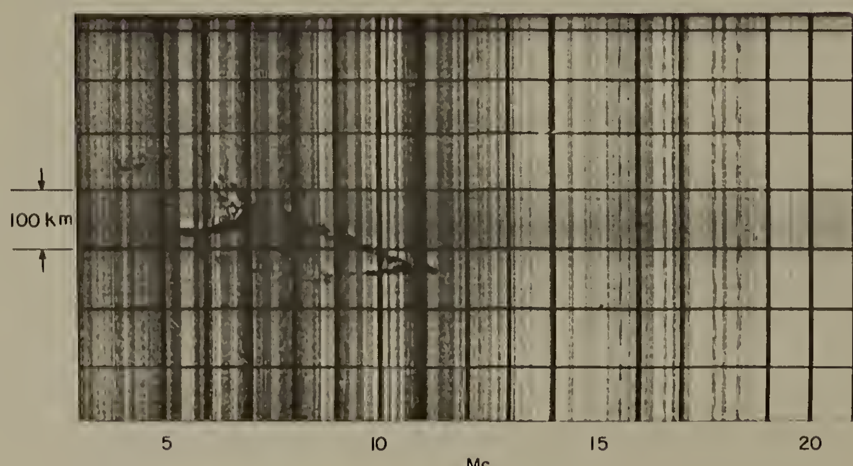
AUGUST 4-5, 1954



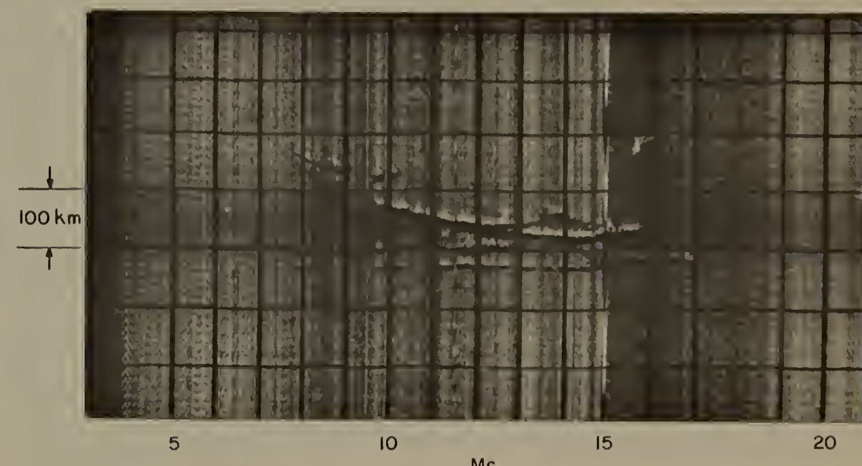
2357



0257



0545



0857

Sterling-Boulder
(Routine)

Sequences Showing Morning Bifurcation of the F layer

April 1, 1954

"Splitting at the bottom": F1 layer develops under the nighttime F layer.

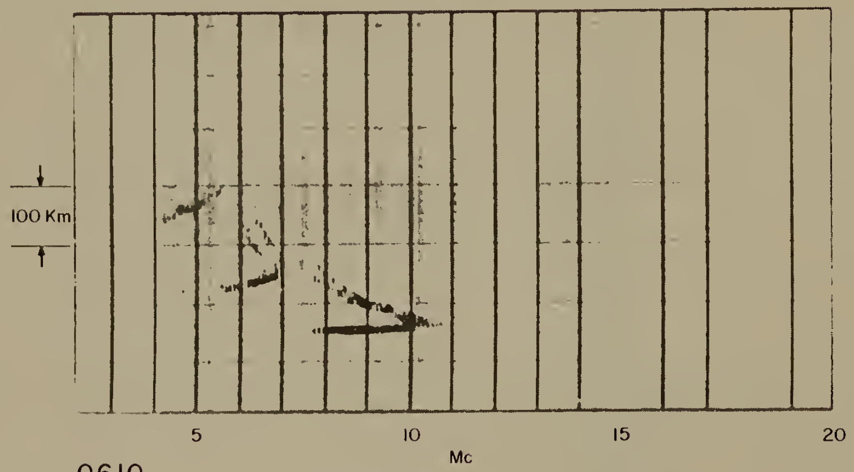
August 11, 1954

Continuity between nighttime F layer and daytime F1 layer.

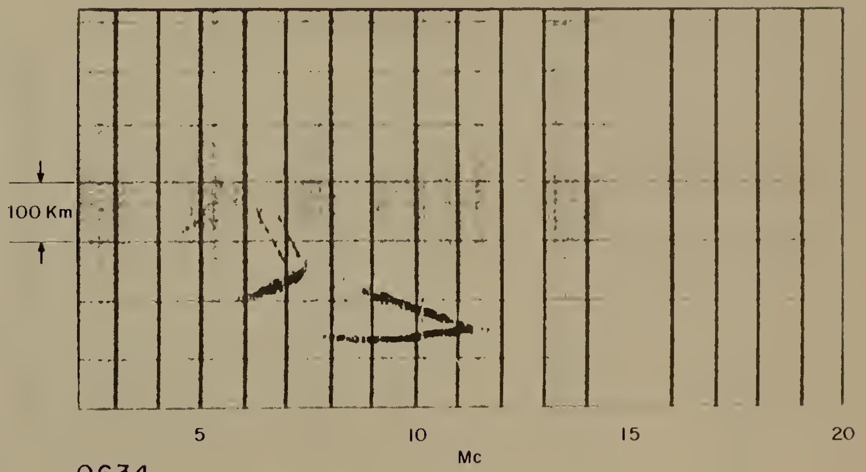
April 14, 1954

"Splitting at the top": Nighttime F layer is continuous with the daytime F1 layer.

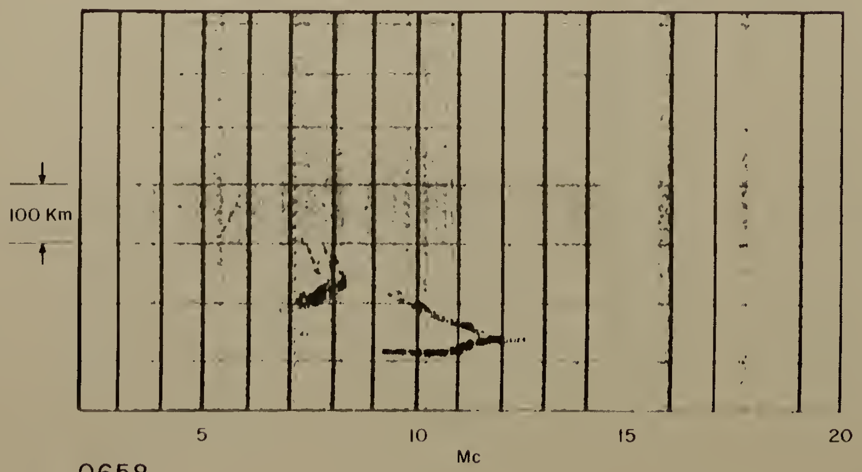
APRIL 1, 1954



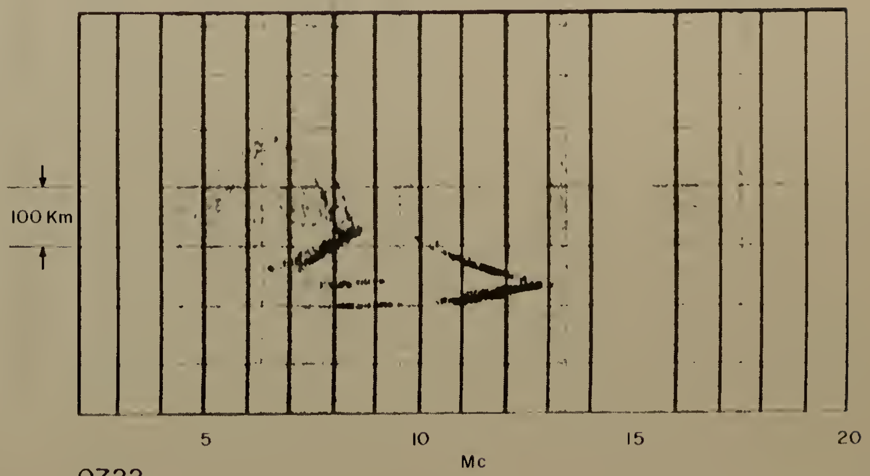
0610



0634

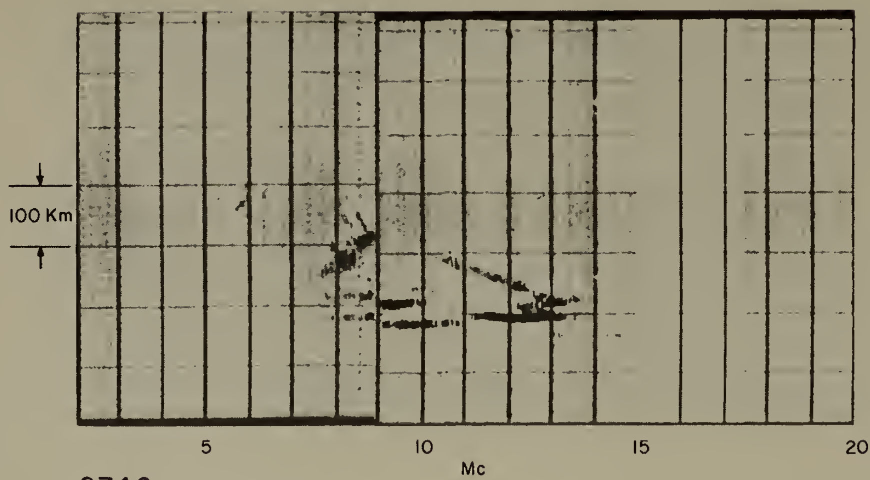


0658

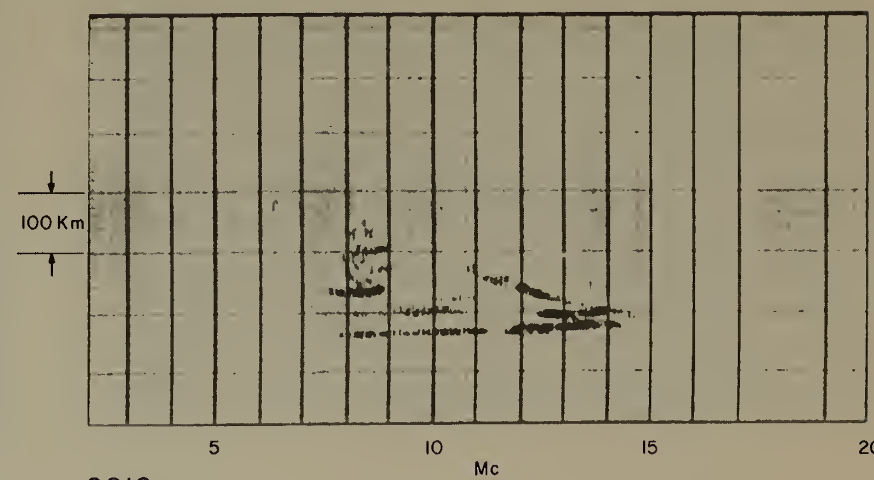


0722

APRIL 1, 1954



0746



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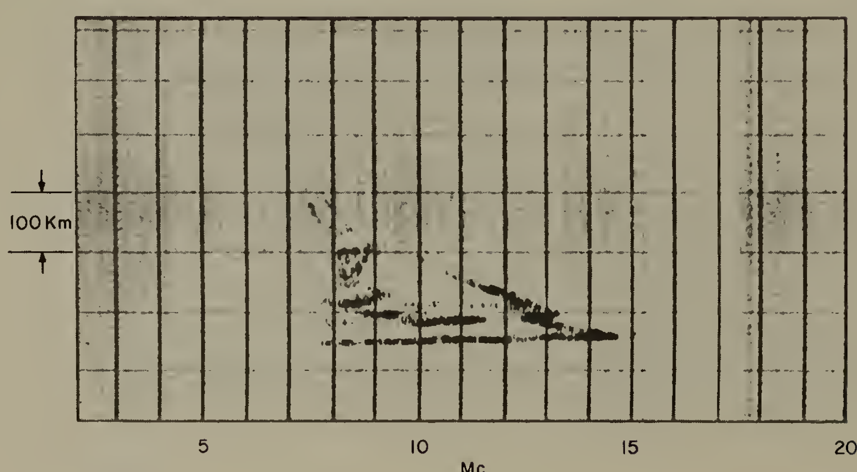
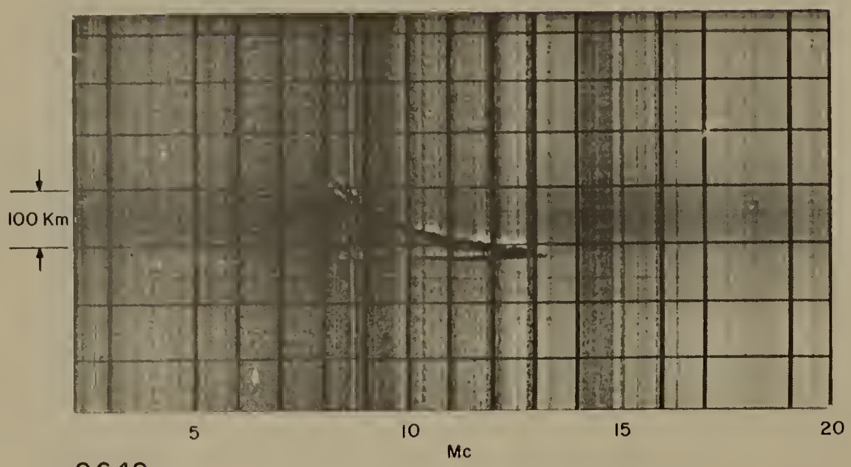
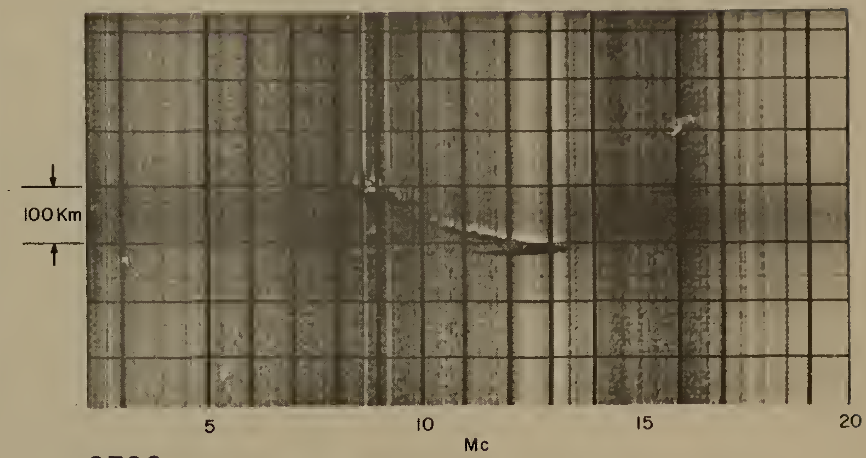


0834

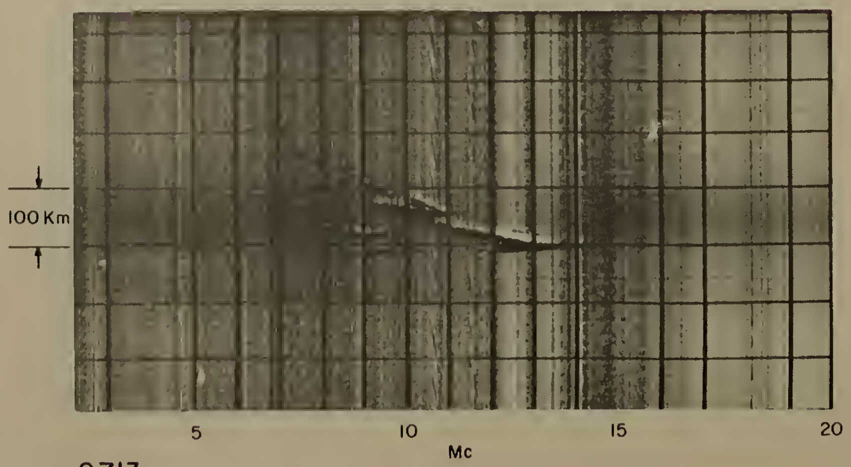
AUGUST 11, 1954



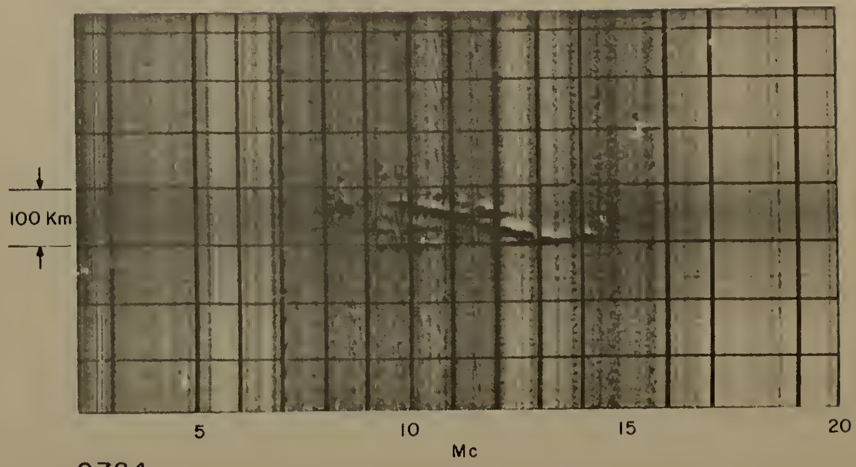
0649



0700

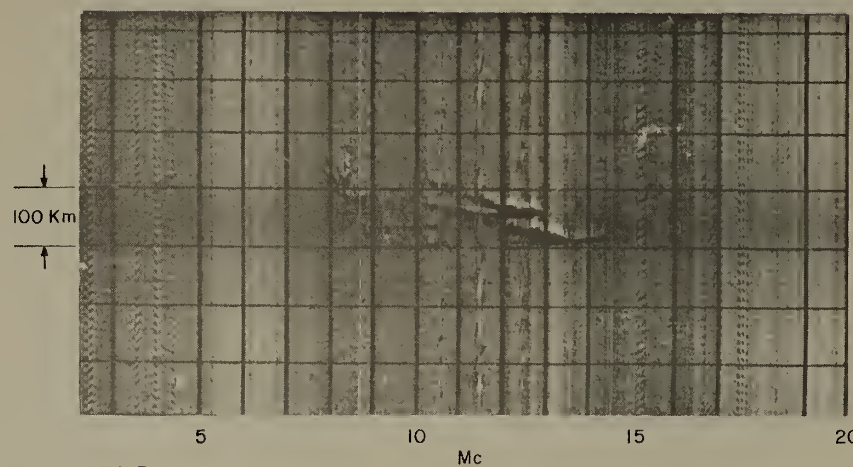


0713

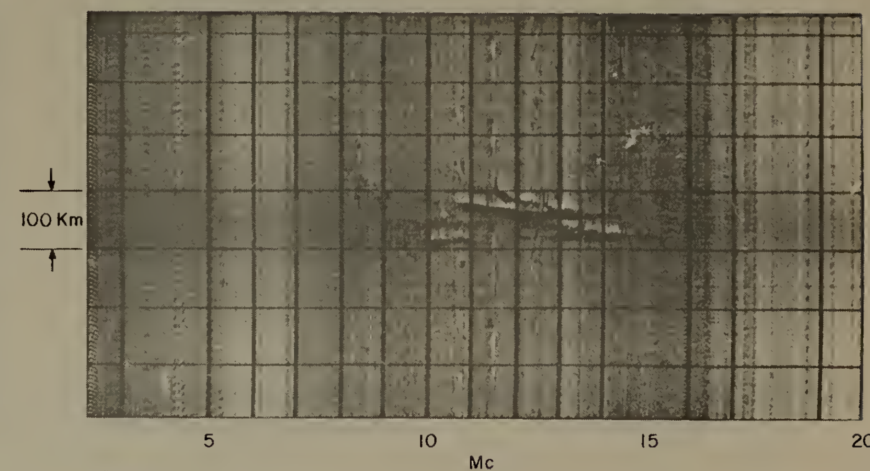


0724

AUGUST 11, 1954



0735



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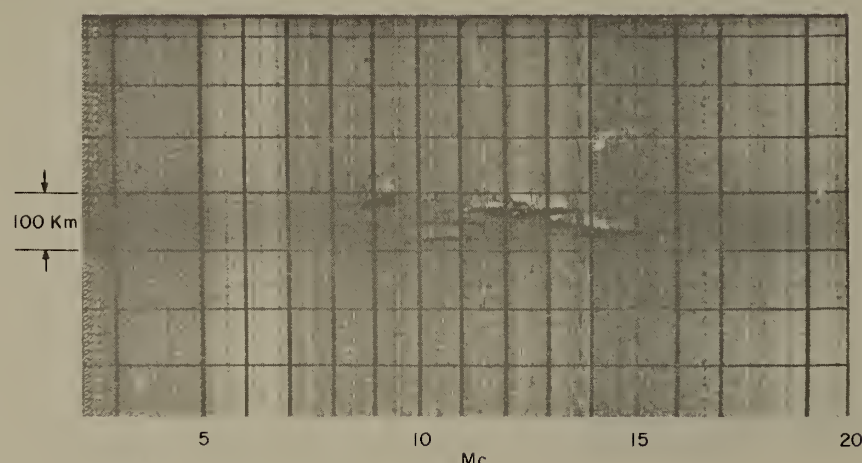
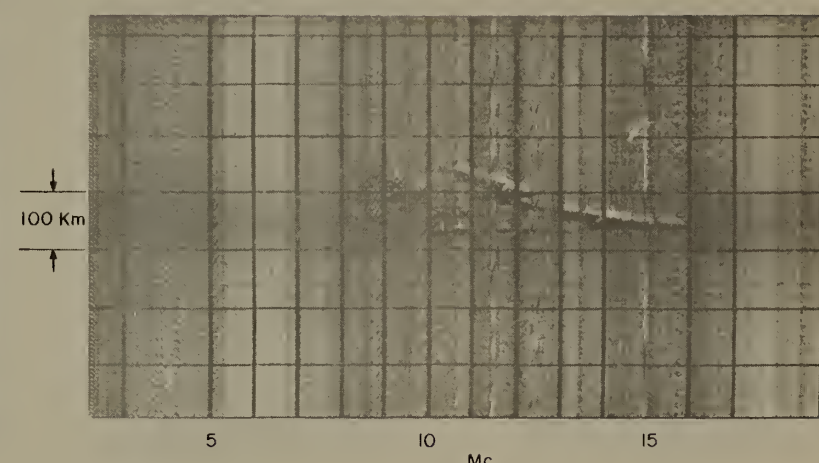
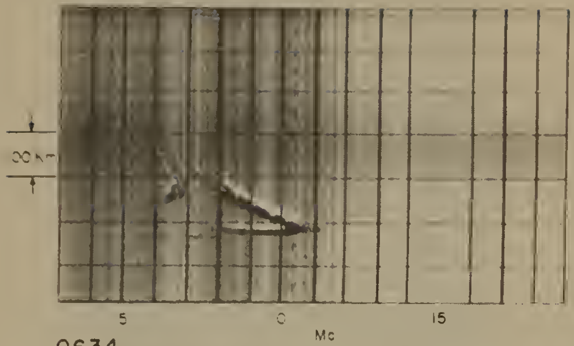


0801



0813



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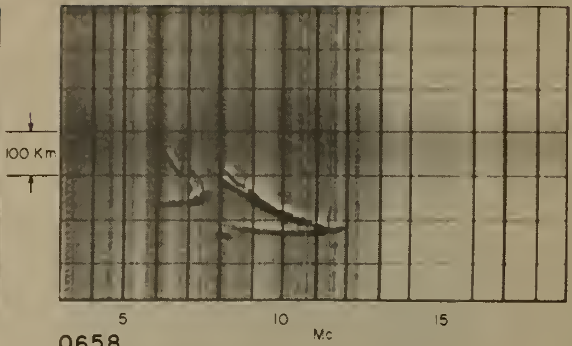

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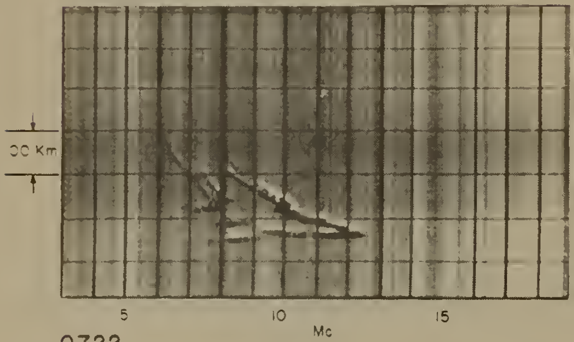
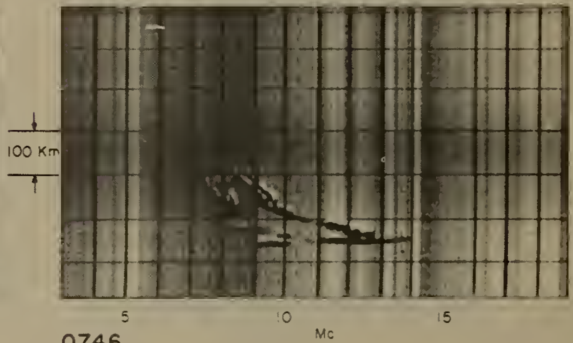
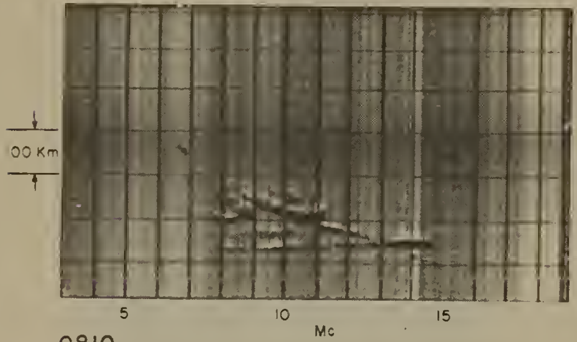


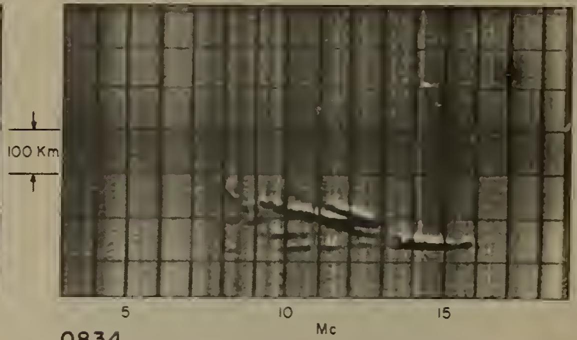
0722



0746



0810



0834

Sterling-Boulder
(Routine)

Miscellaneous Sequences

November 5, 1953

Oblique-incidence records showing development of apparent stratifications, possibly produced by "off-path" reflections. Some ionospheric roughness indicated by slight spread and presence of Z-trace on vertical-incidence records.

November 12, 1953

Complexities in oblique-incidence records, perhaps associated with "oblique" reflection and forked trace evident on the midpoint vertical-incidence ionograms shown.

June 23, 1954

Sporadic E reflections out to 24 Mc; pronounced MUF extension.

July 21, 1954

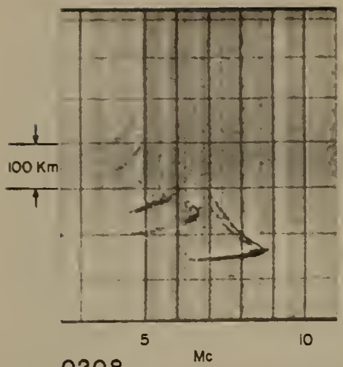
Complex nose structure; Es reflections.

August 25, 1954

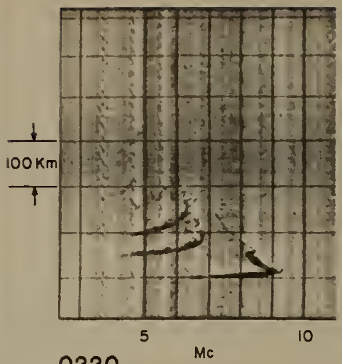
Es evident from traces between those for 1XF and 2XF. Complex nose structure.

November 12, 1953

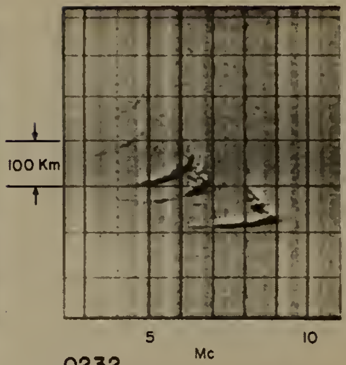
Apparent stratification and inner "nose". (See footnote in Section III-3)



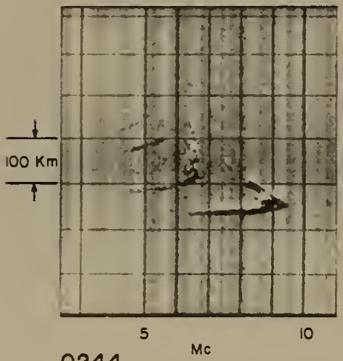
0208



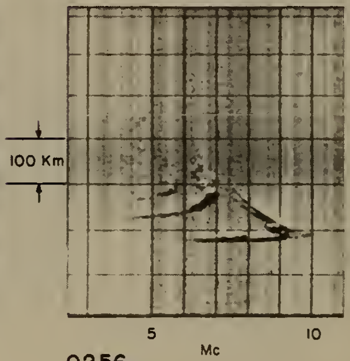
0220



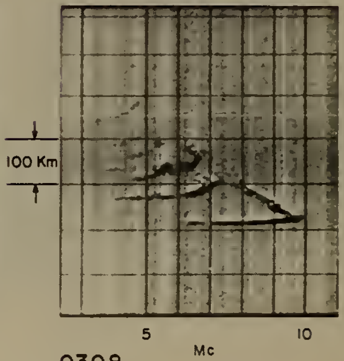
0232



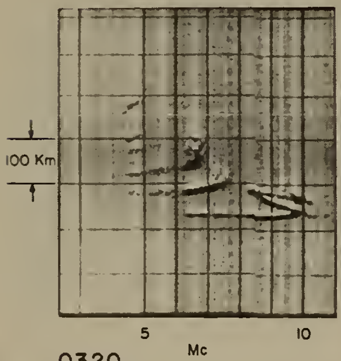
0244



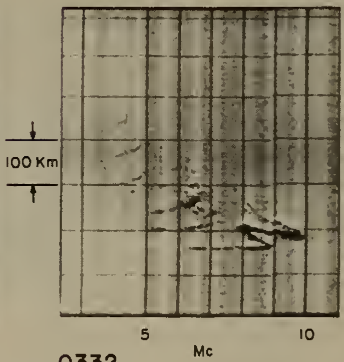
0256



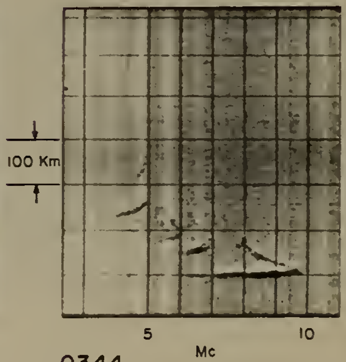
0308



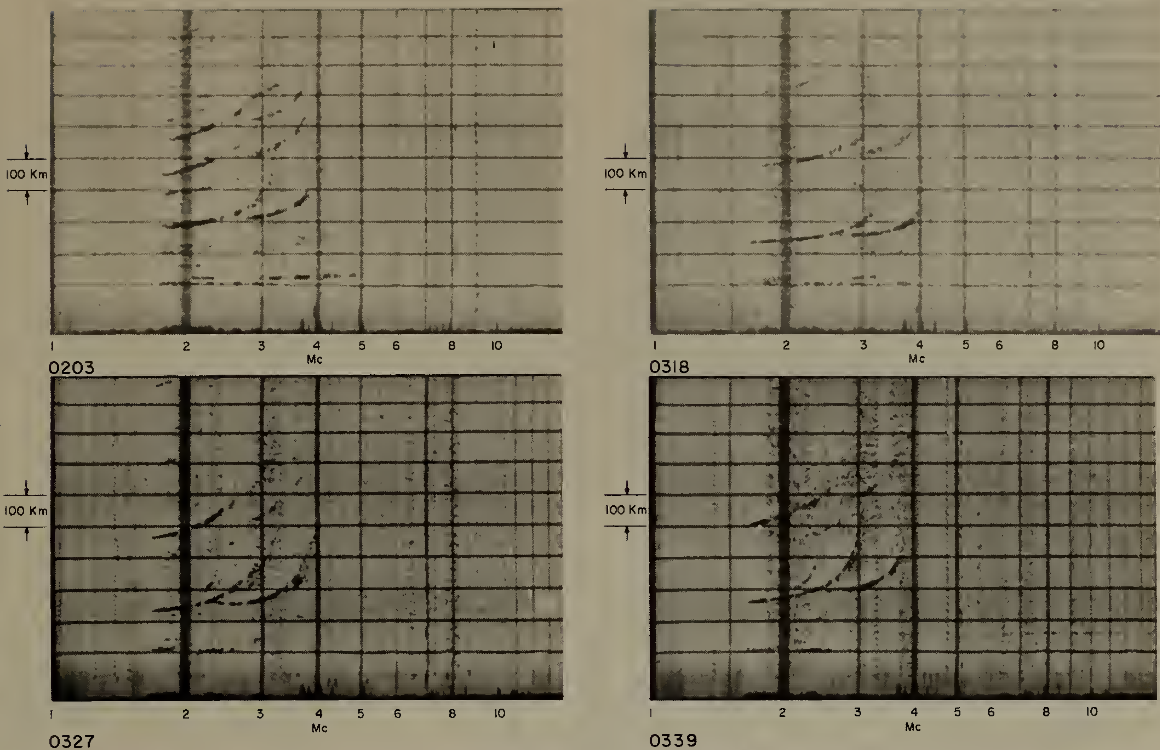
0320



0332

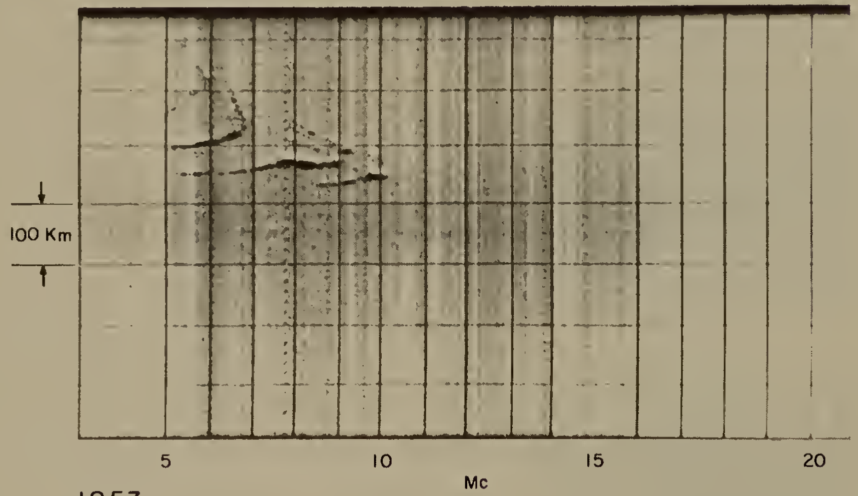


0344

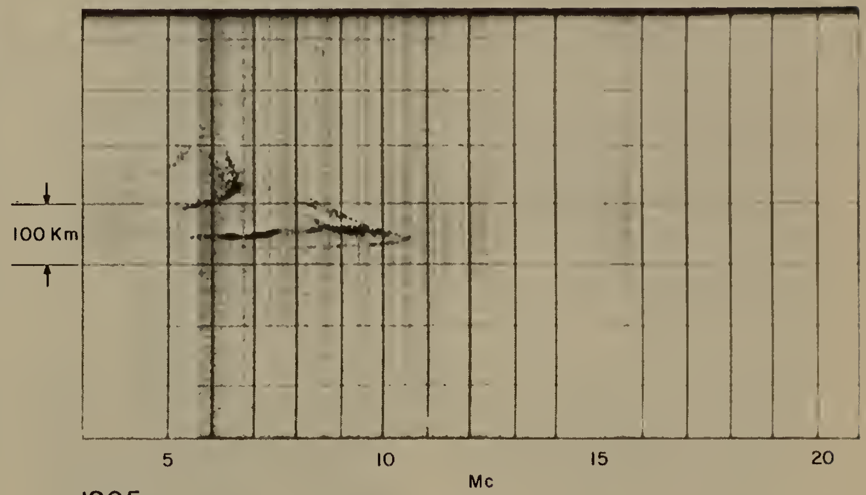


MIDPOINT VERTICAL INCIDENCE

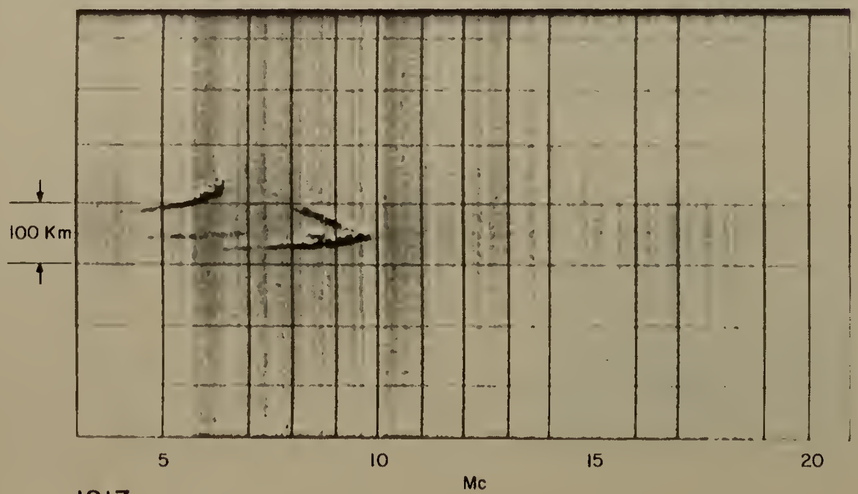
NOVEMBER 12, 1953



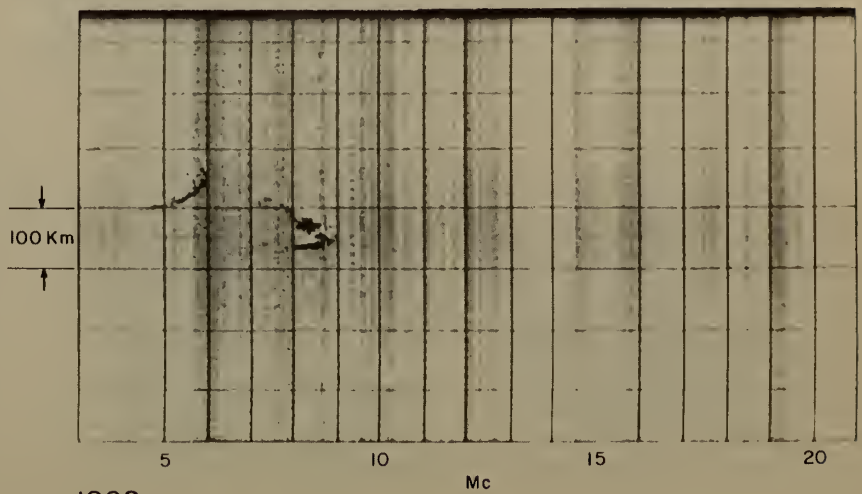
1853



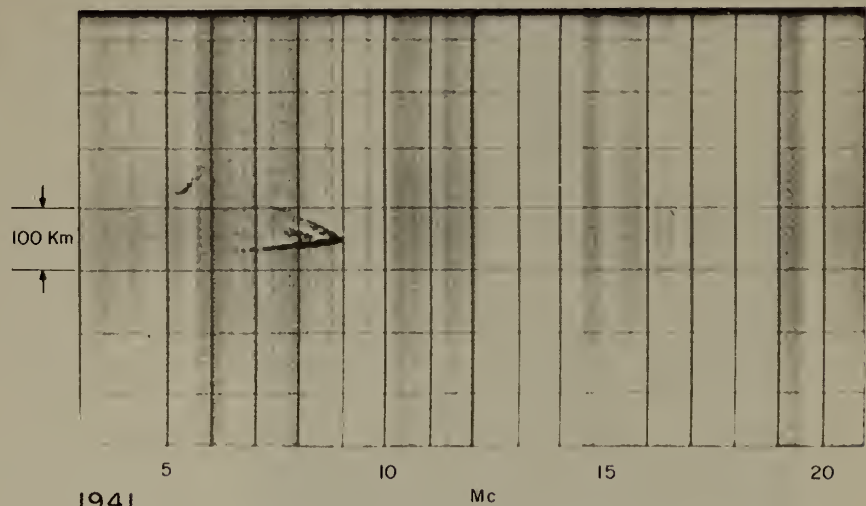
1905



1917

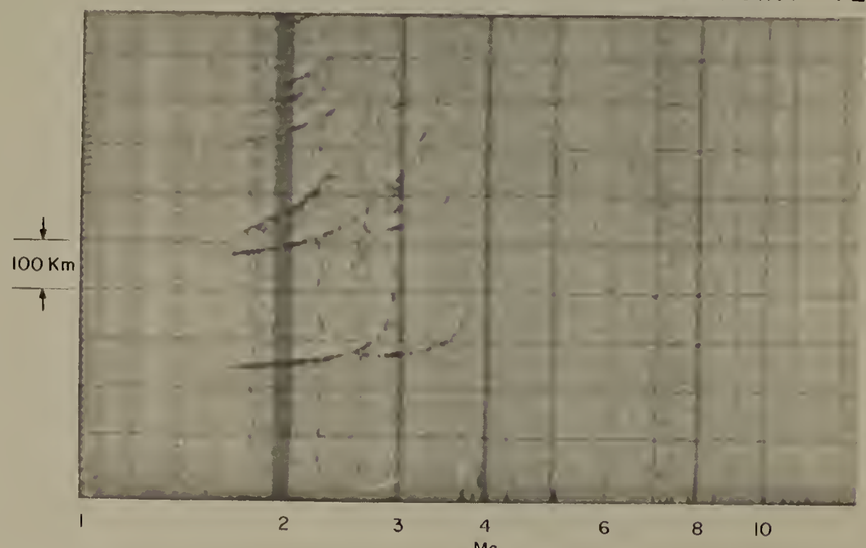


1929

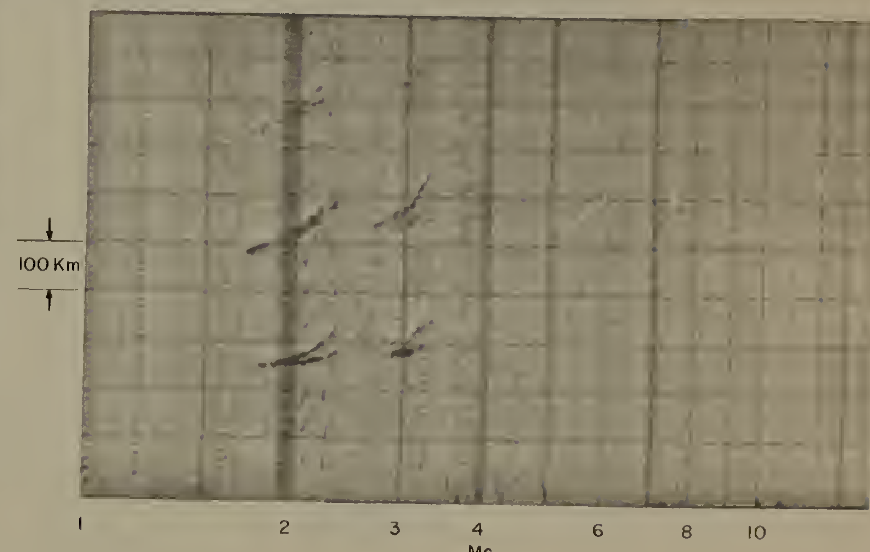


1941

MIDPOINT VERTICAL INCIDENCE

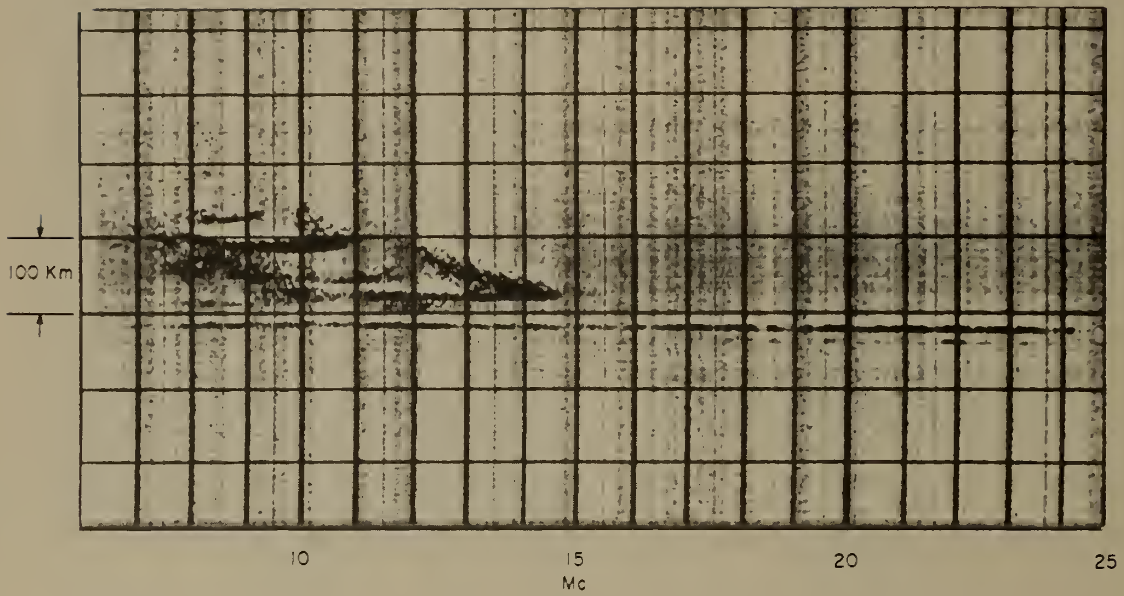


1912

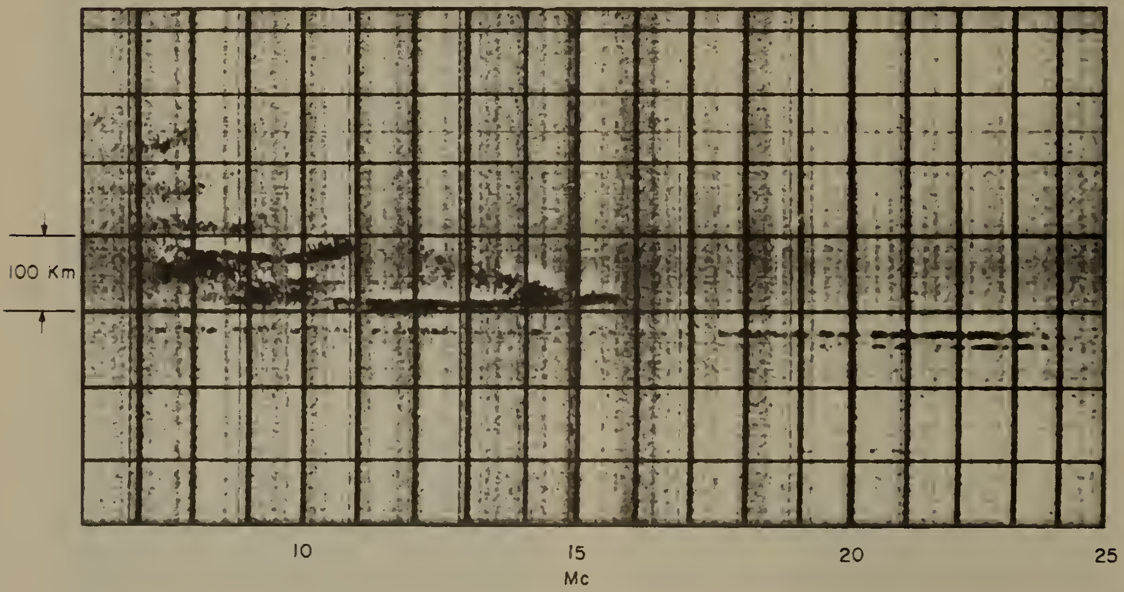


1933

JUNE 23, 1954

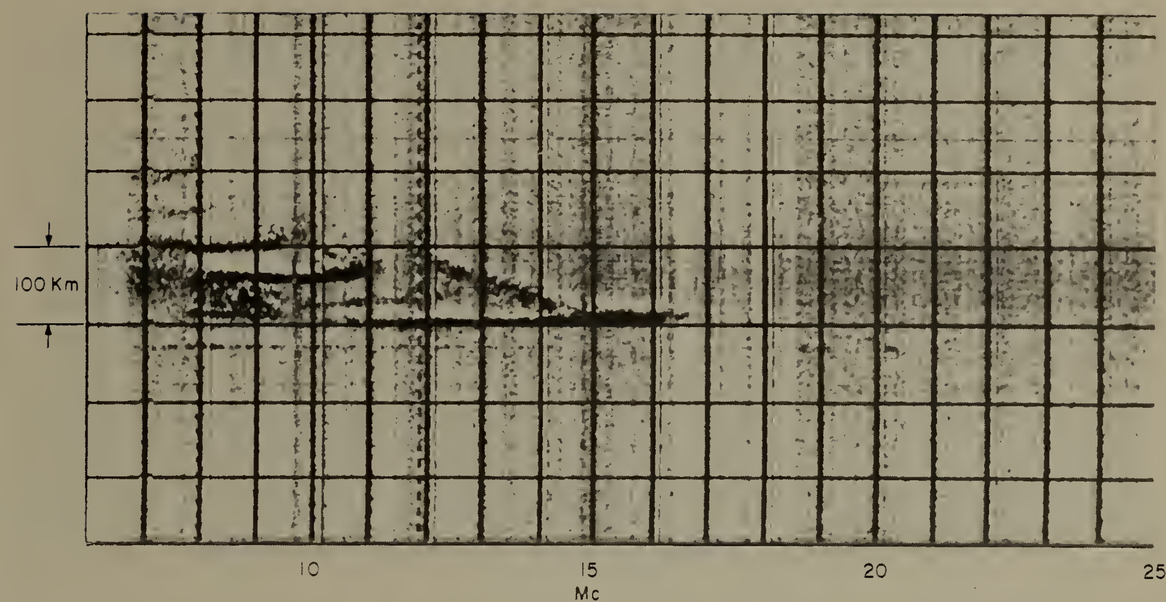


1803

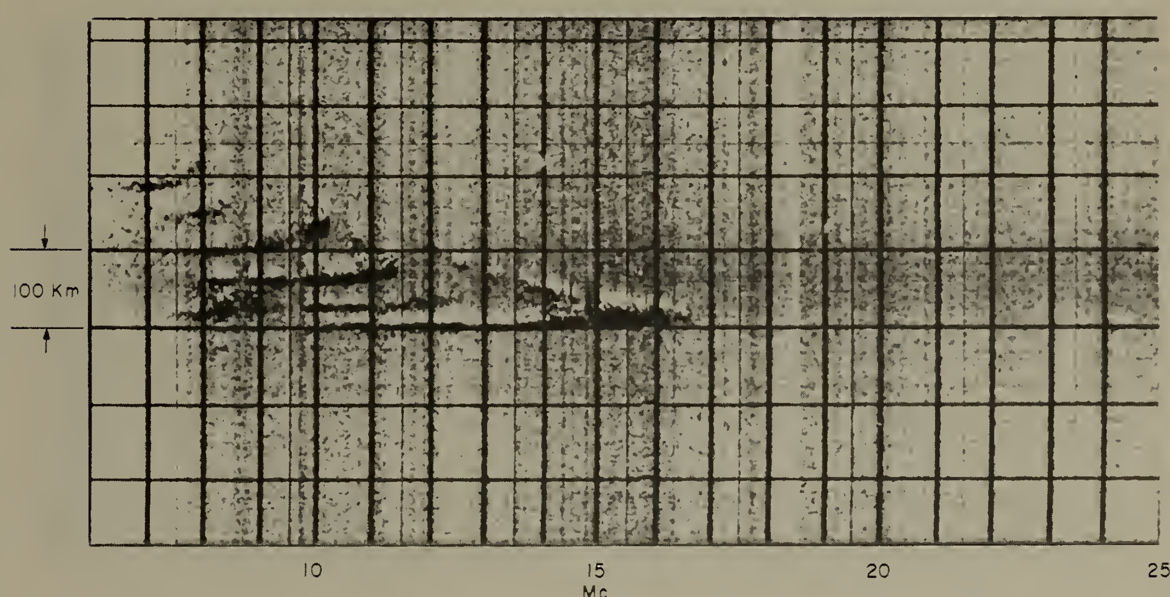


1815

JUNE 23, 1954

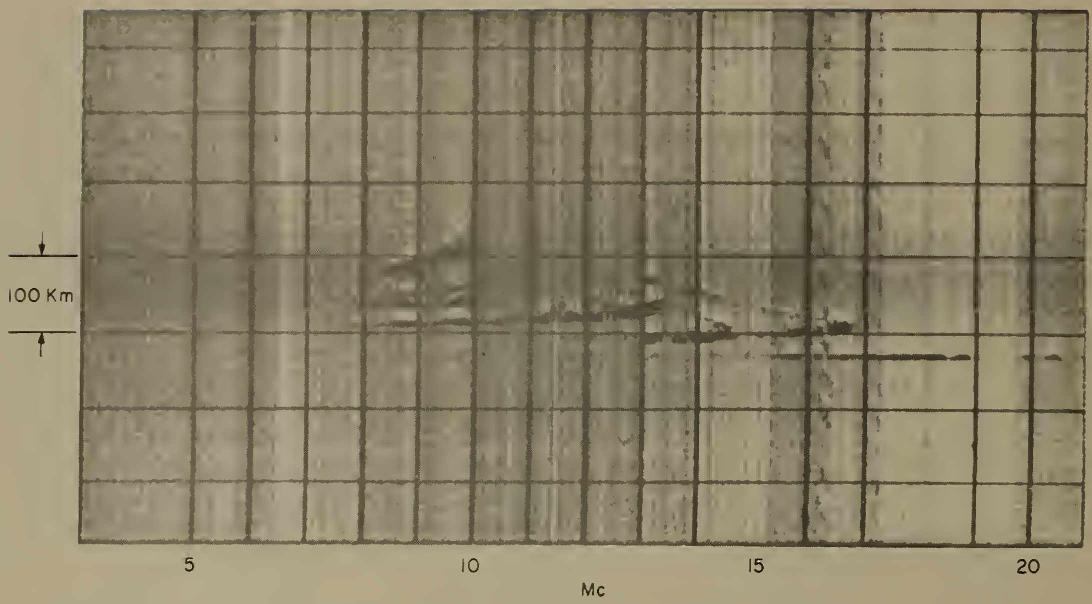


1827

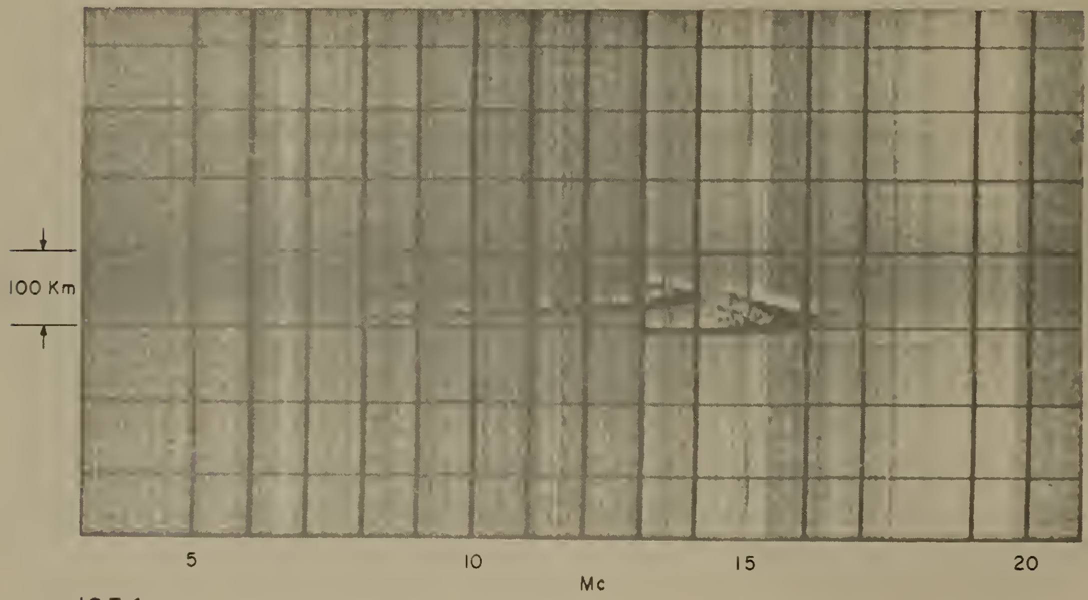


1839

JULY 21, 1954

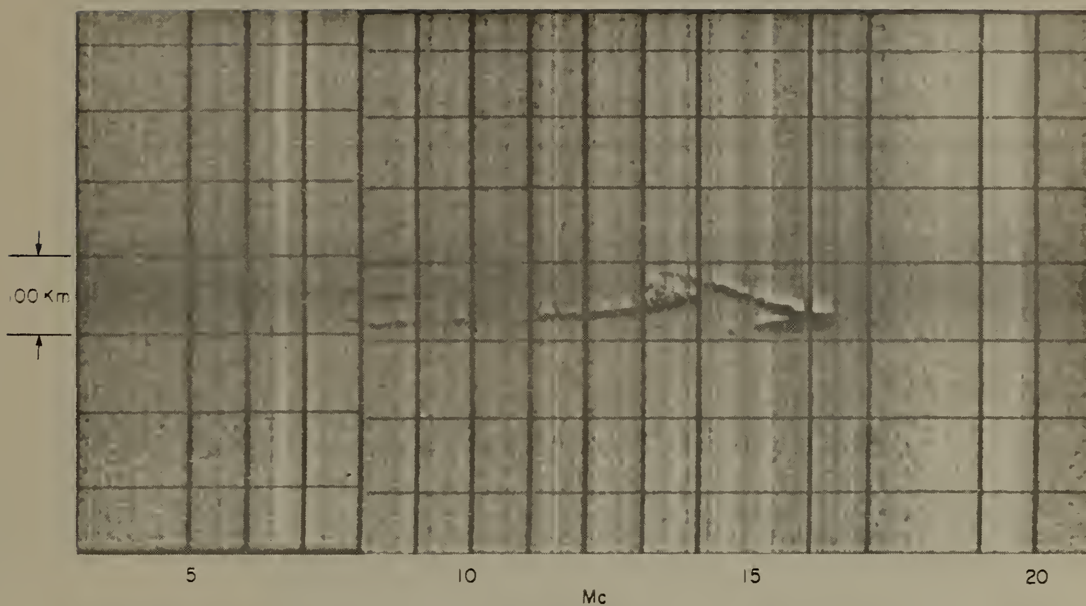


1922

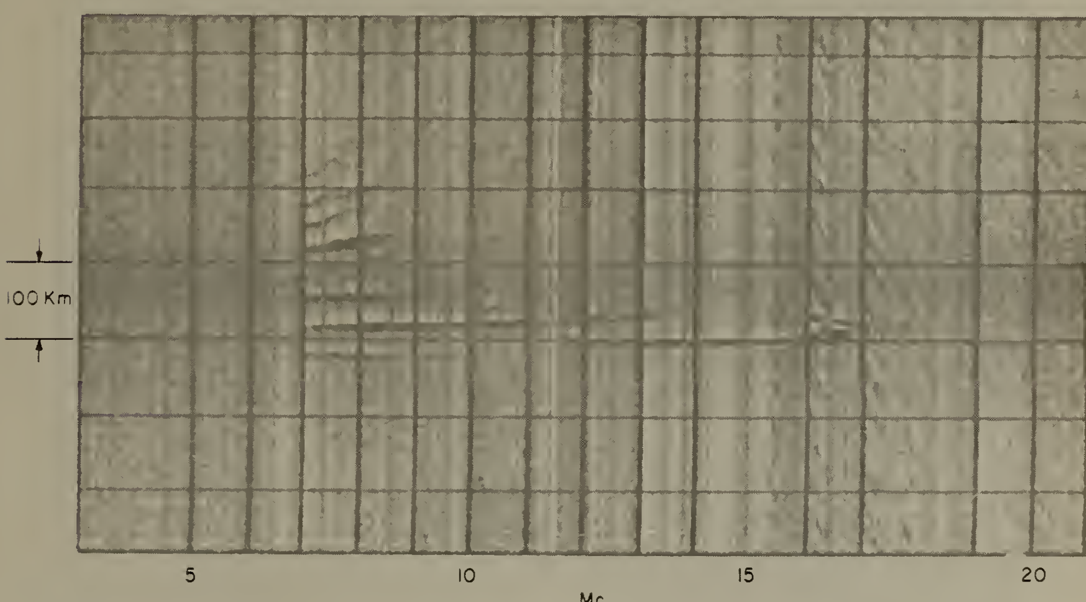


1934

JULY 21, 1954

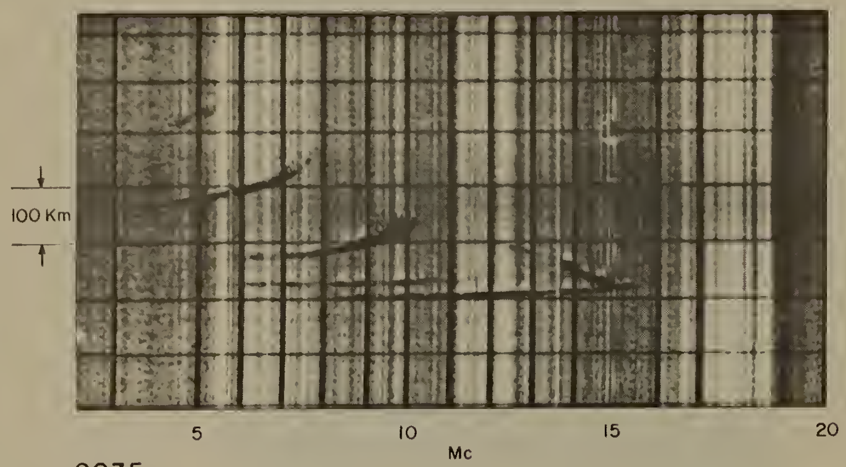


1946

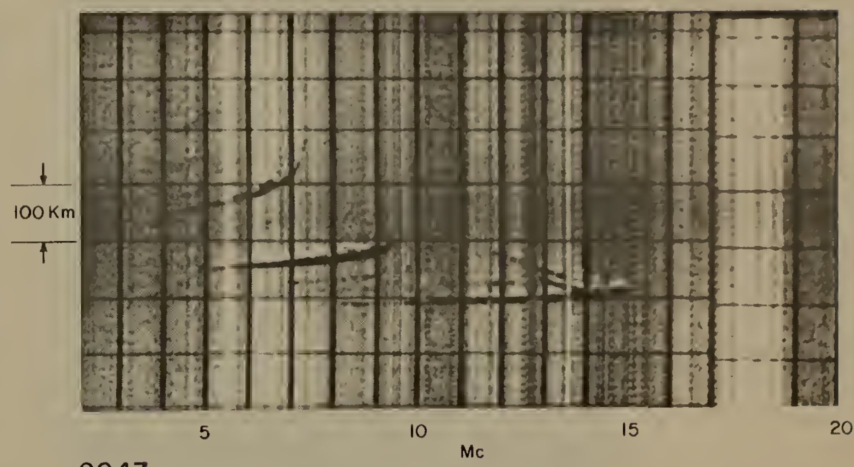


1958

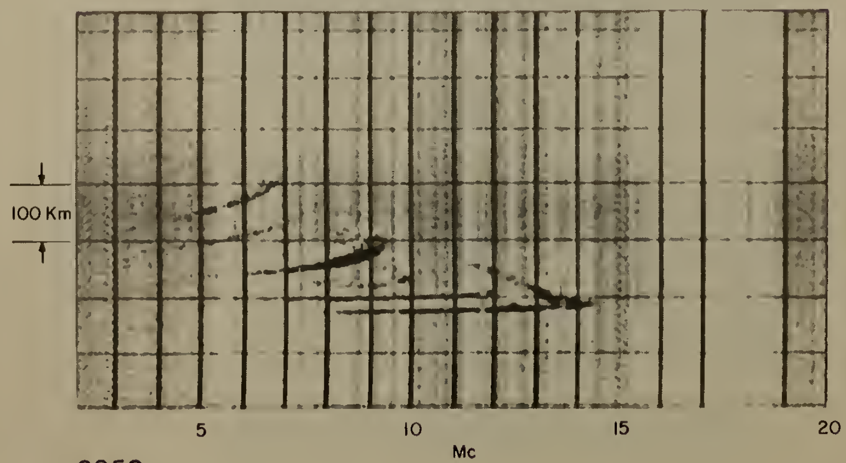
AUGUST 25, 1954



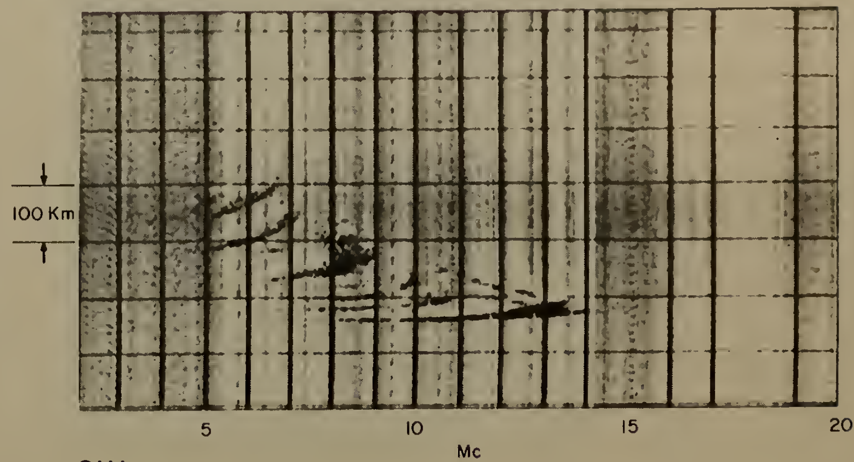
2035



2047

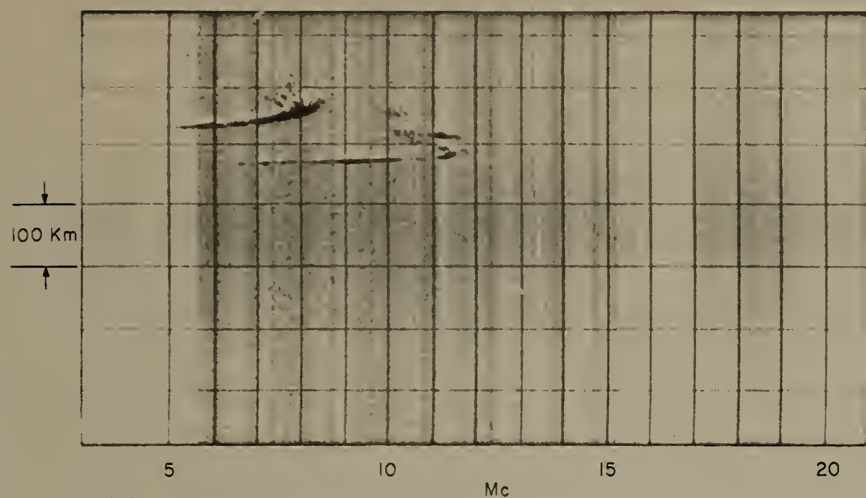


2059

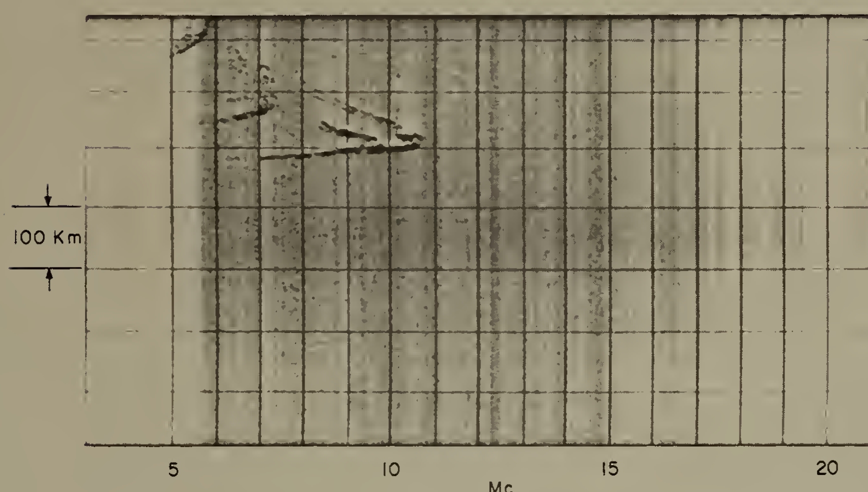


2111

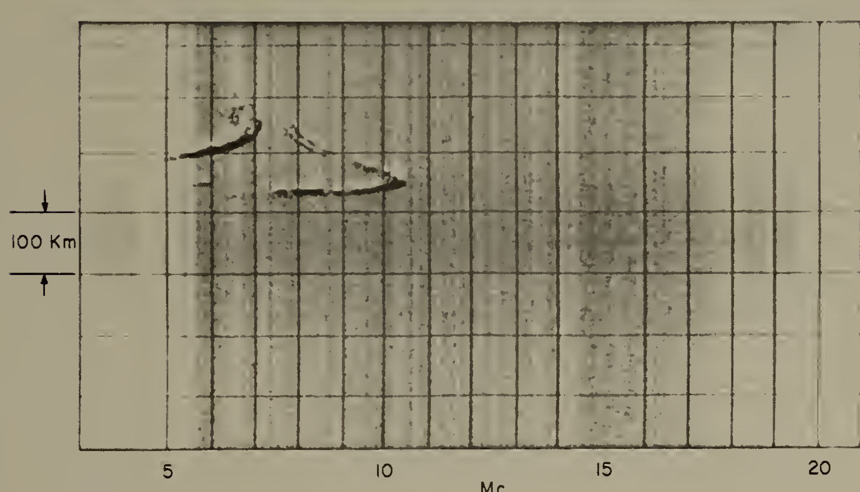
NOVEMBER 12, 1953



1805



1817



1829

Sterling-Boulder
(Routine)

Miscellaneous Ionograms

January 7, 1954

Five F-layer modes present

July 22, 1954

The record indicates the difficulty encountered in specifying exactly the F1 MUF for this path.

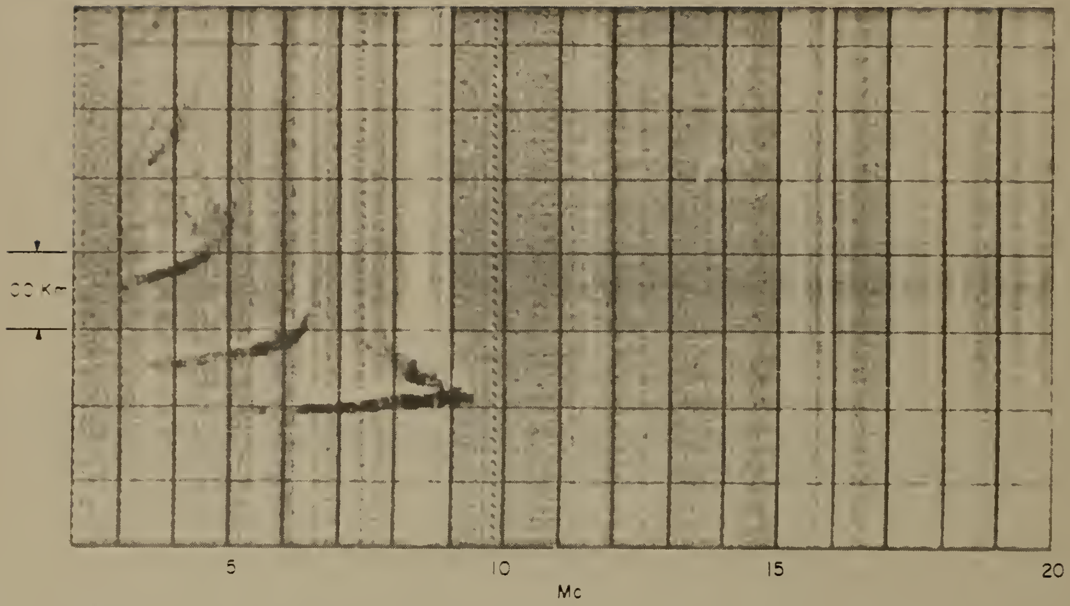
August 25, 1954

E2, F1, and F2 traces evident.

April 5, 1955

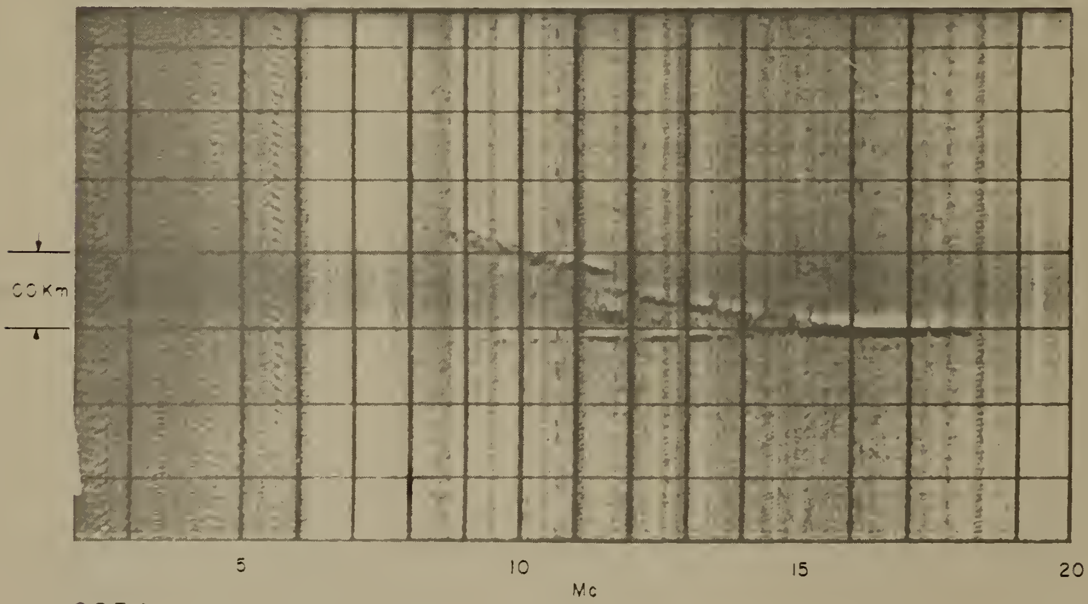
The Pedersen ray gives a clear indication of the increase in O-X frequency separation as the angle of incidence increases.

JANUARY 7, 1954



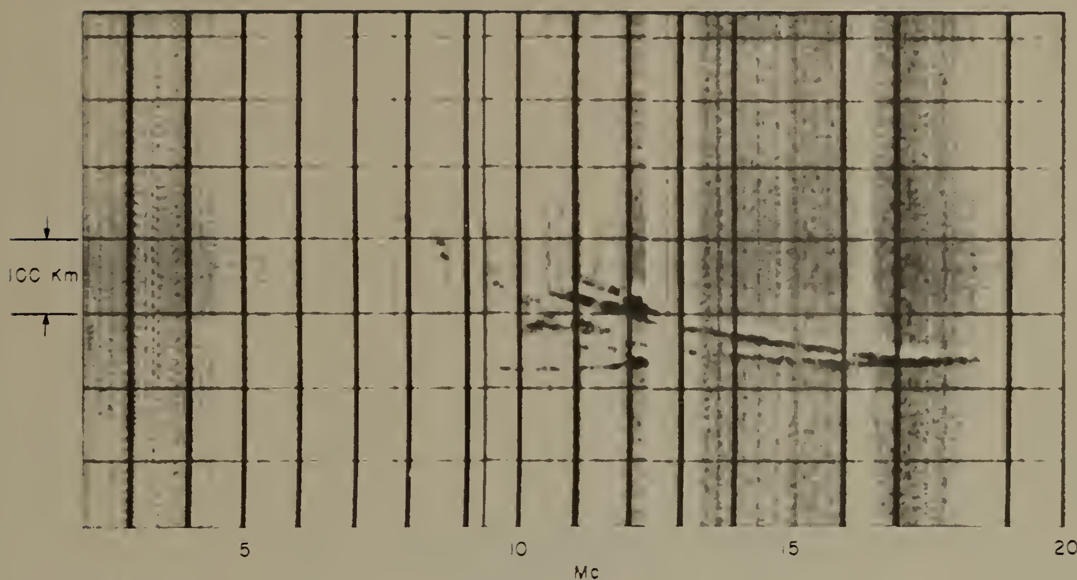
0517

JULY 22, 1954



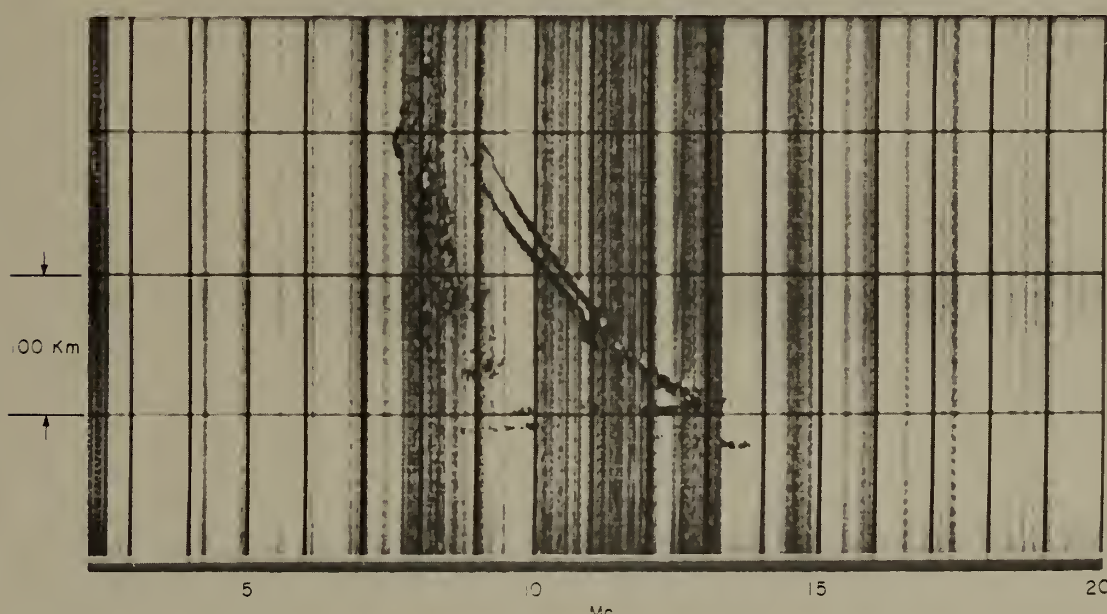
0934

AUGUST 25, 1954



1059

APRIL 5, 1955



1647

III. Sterling-Boulder - 2370 km
(Experimental)

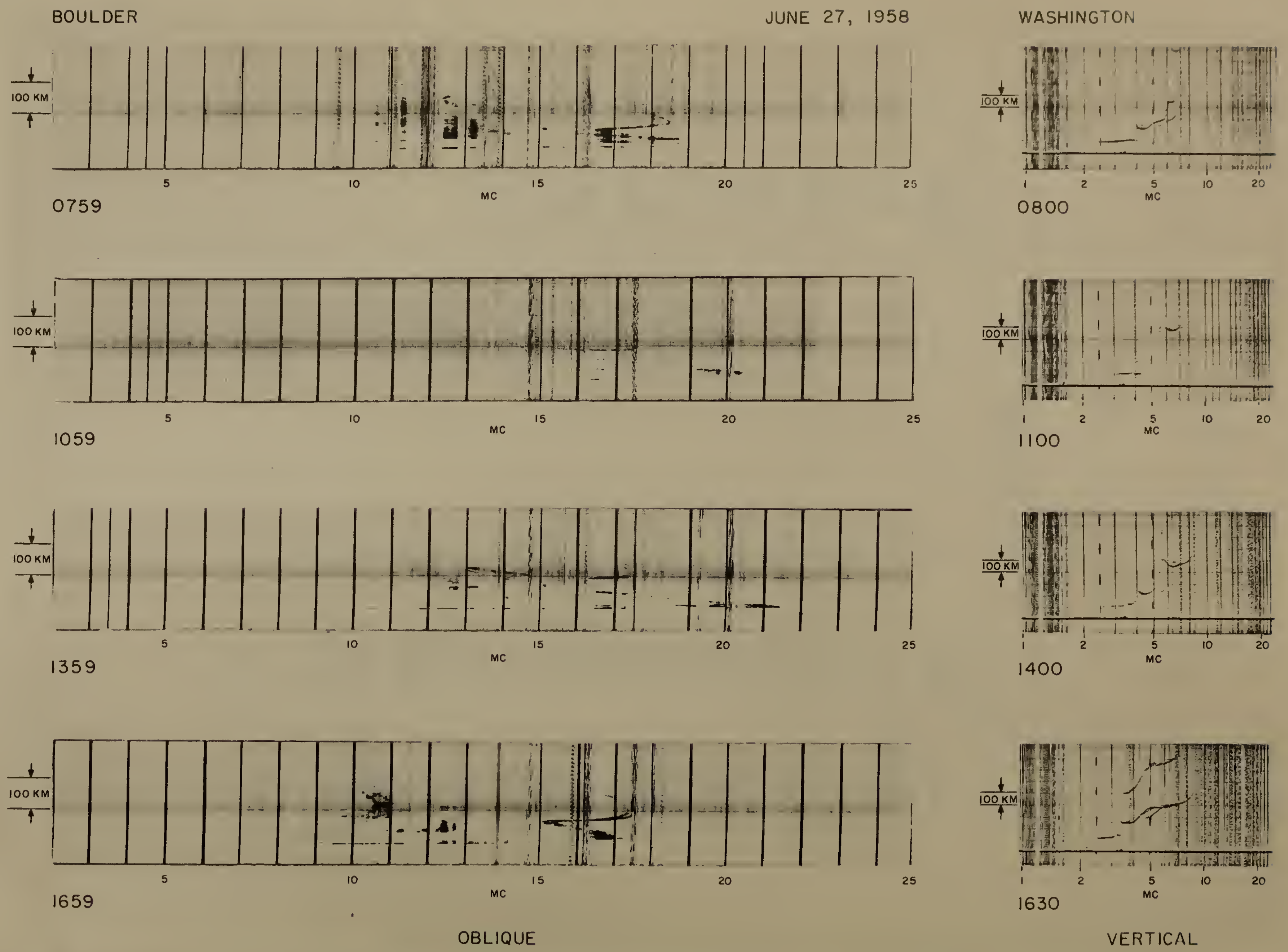
(All ionograms with expanded frequency scales
were made using 20 μs pulses)

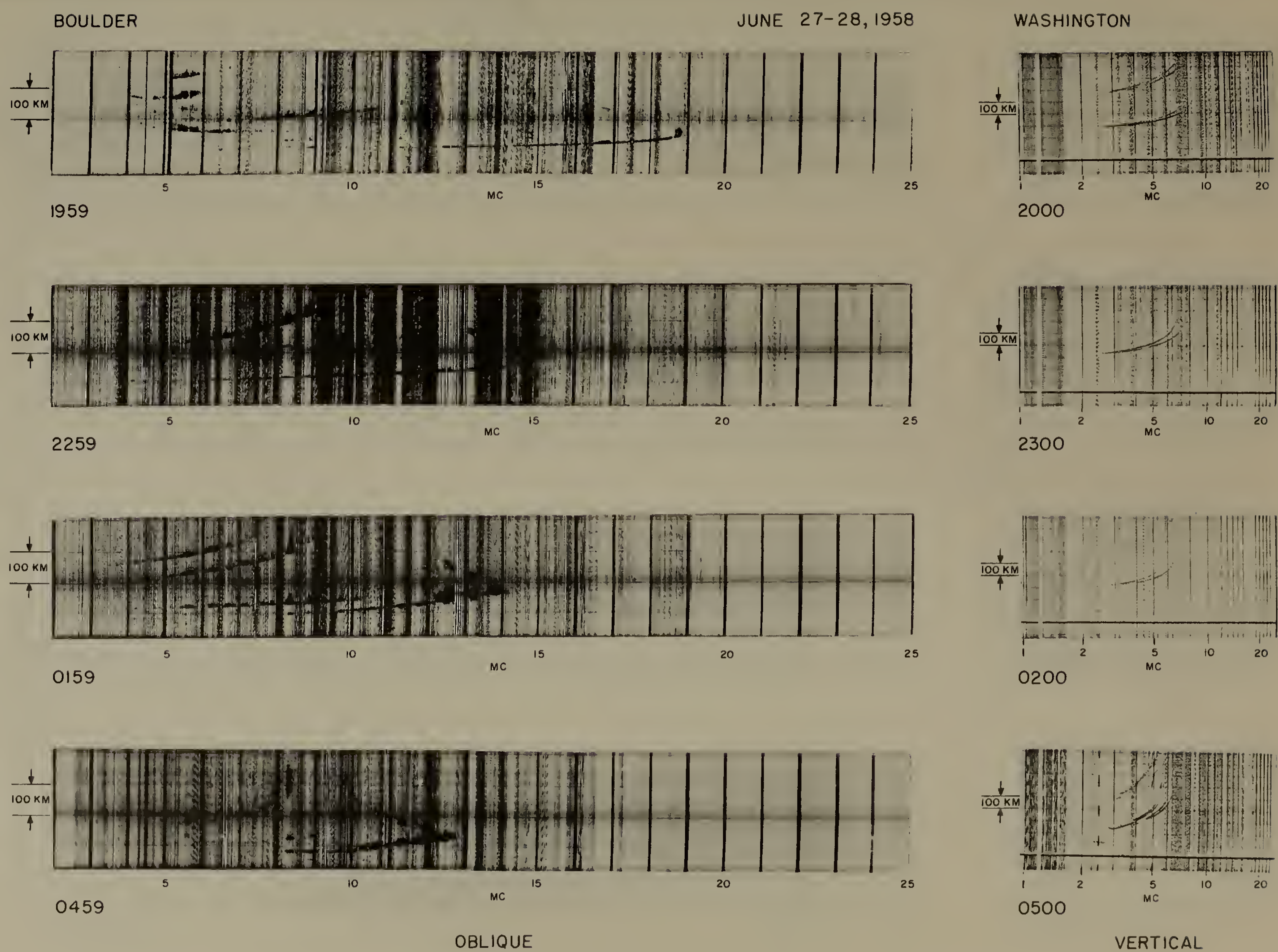
Sterling-Boulder
(Experimental)

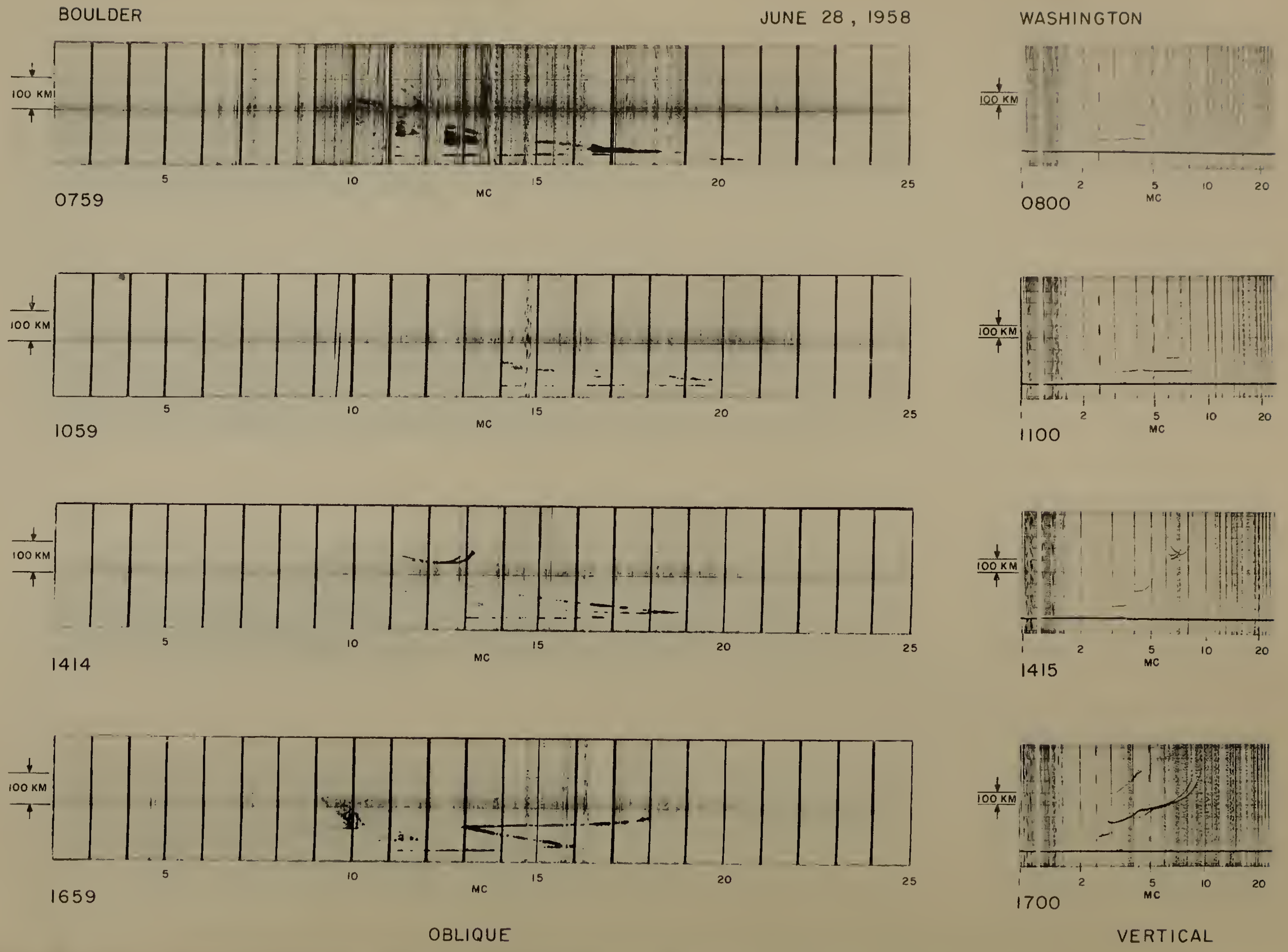
June 28-29, 1958 Magnetic Storm

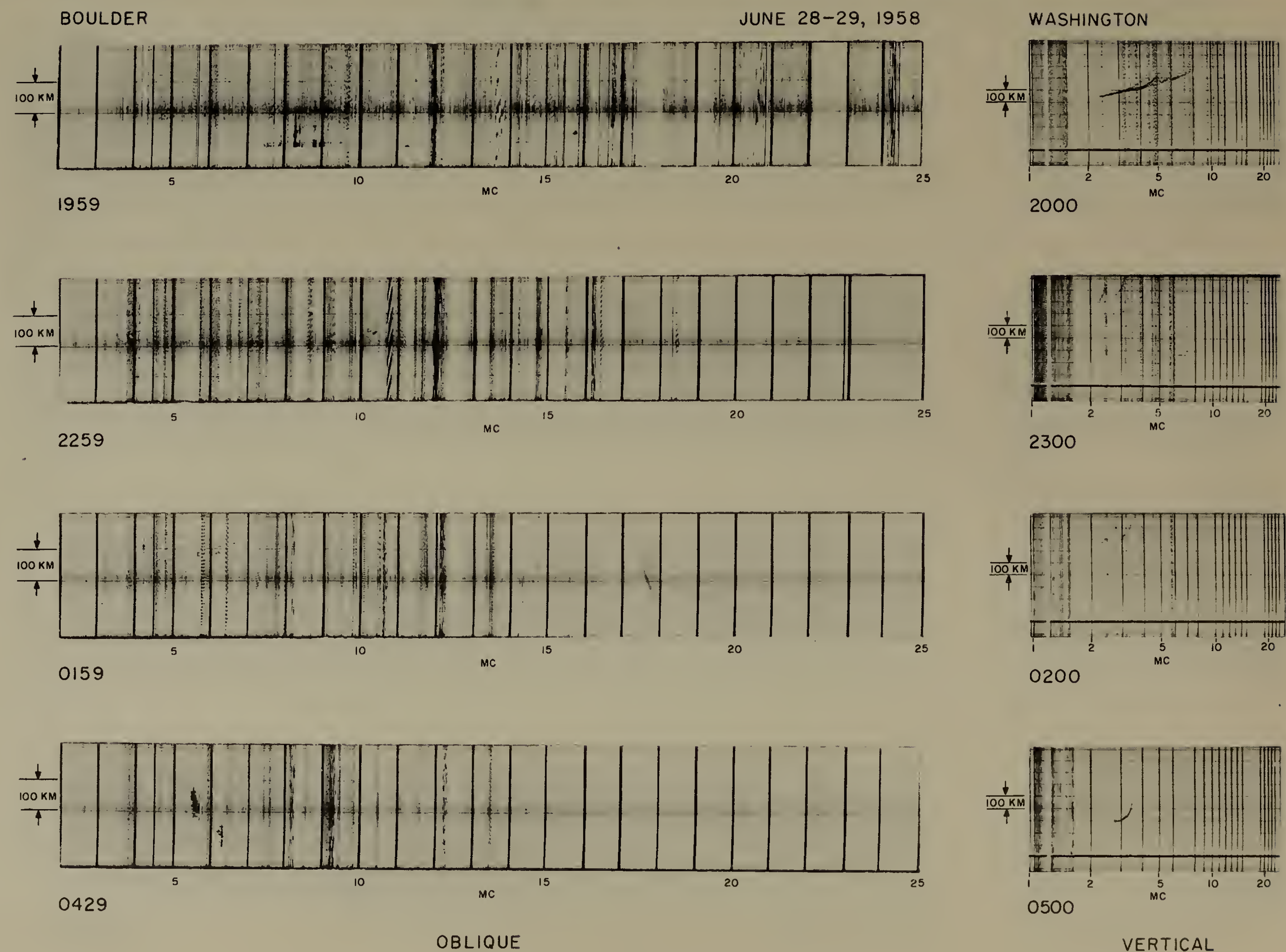
Ionogram Series from Quiet Day before Storm
to Quiet Day after Storm

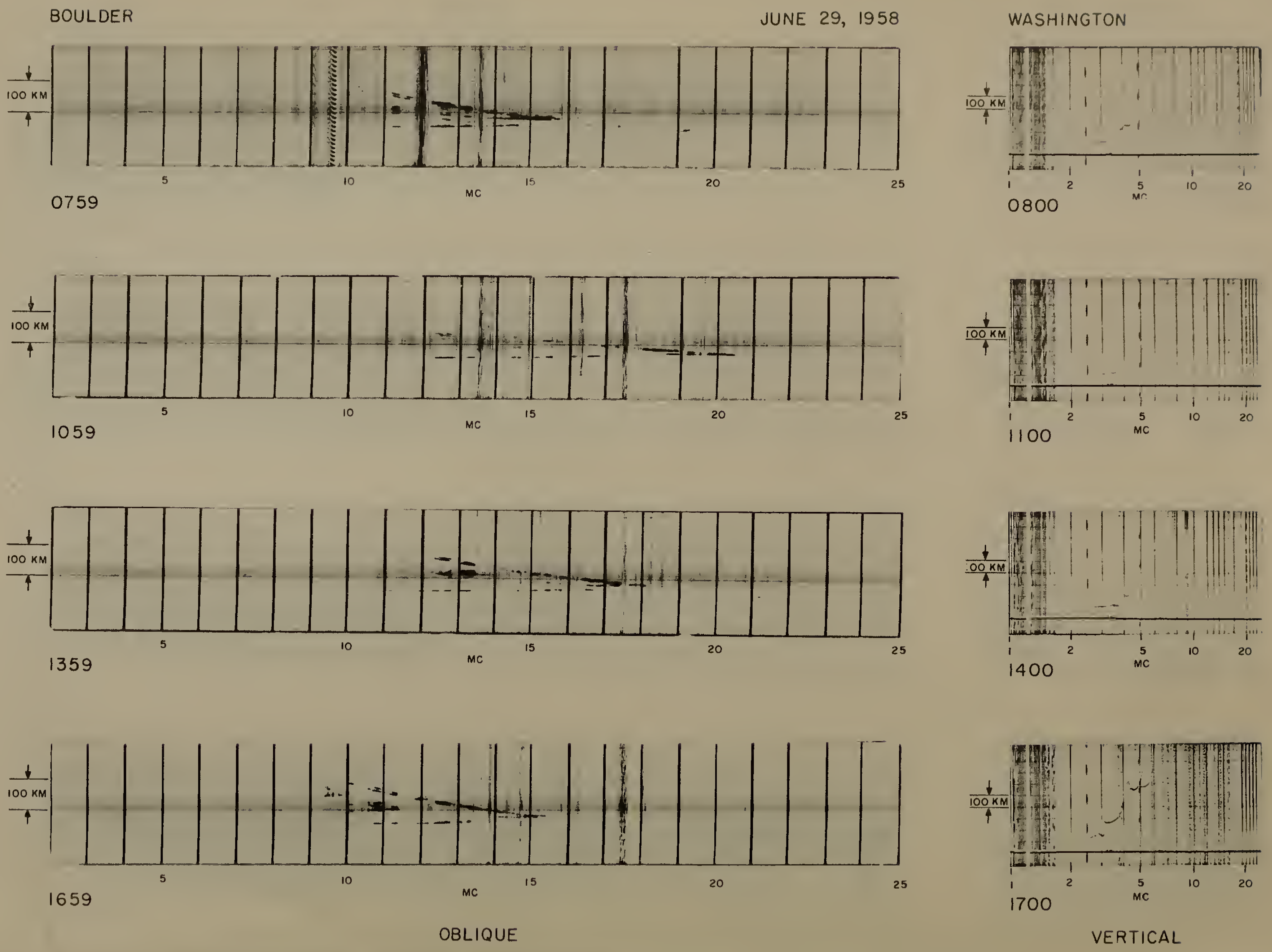
Date	Midpoint Time	K_p	Date	Midpoint Time	K_p
6/27/59	0759	1+	6/29/59	0759	8-
	1059	1+		1059	6+
	1359	1+		1359	4+
	1659	3o		1659	3-
	1959	2+		1959	2o
	2259	3+		2259	3-
6/28/59	0159	4o	6/30/59	0152	2-
	0459	4-		0459	1+
	0759	3o		0759	2-
	1059	5-		1059	3-
	1414	7o		1407	3o
	1659	8-		1559	2+
	1959	7o			
	2259	8o			
6/29/59	0159	7-			
	0429	7o			

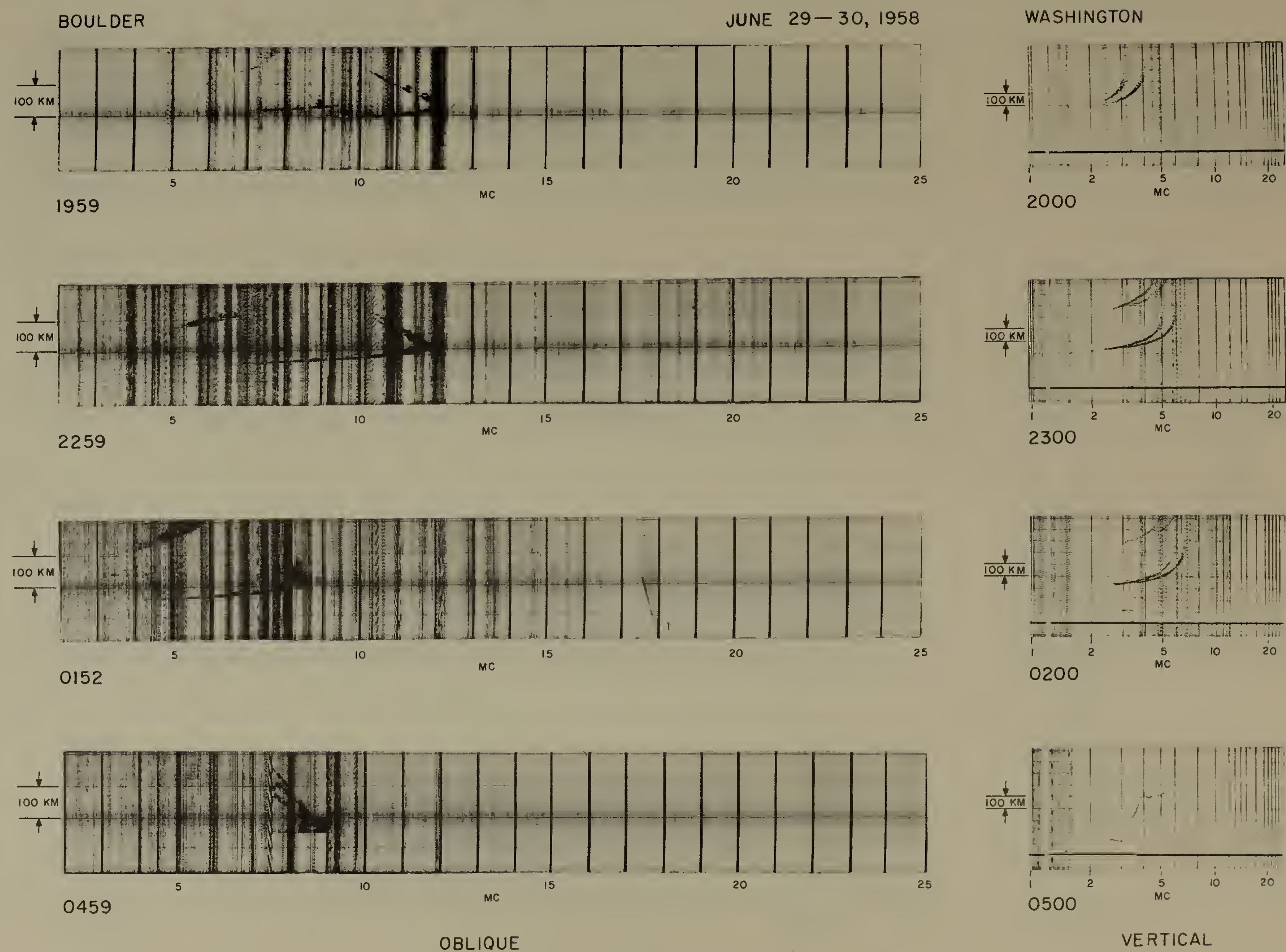

BOULDER
JUNE 27, 1958
WASHINGTON
100 KM
0759
0800
1059
1100
1359
1400
1659
1630
MC
OBLIQUE
VERTICAL

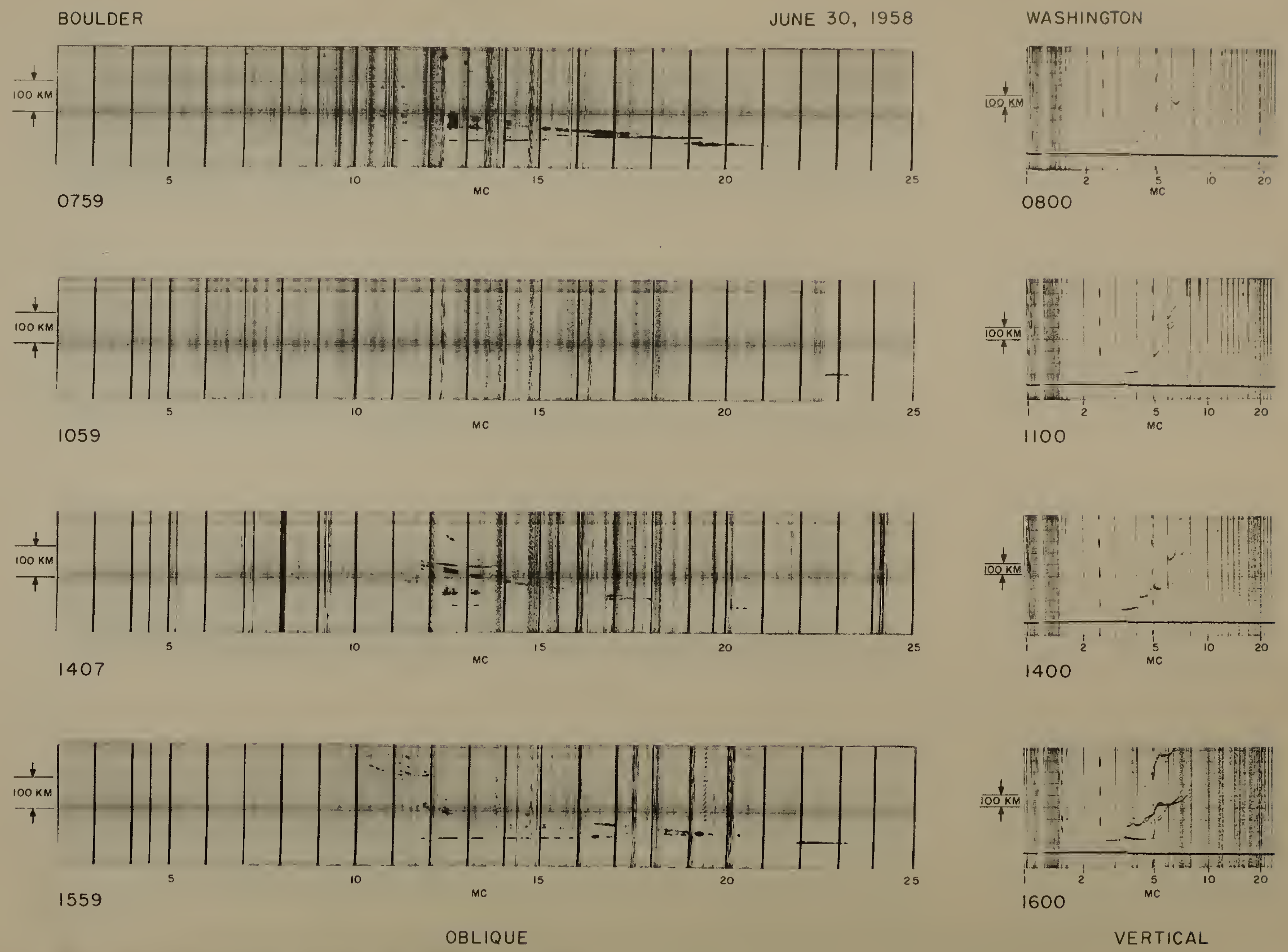

BOULDER
JUNE 27-28, 1958
WASHINGTON
100 KM
5
10
15
20
25
MC
1
2
5
10
20
1959
2000
2259
2300
0159
0200
0459
0500
OBLIQUE
VERTICAL


BOULDER
JUNE 28, 1958
WASHINGTON
100 KM
0759
5
10
15
20
25
MC
0800
1
2
5
10
20
MC
1059
1100
1414
1415
1659
1700
OBLIQUE
VERTICAL


BOULDER
JUNE 28-29, 1958
WASHINGTON
100 KM
MC
1959
2000
2259
2300
0159
0200
0429
0500
OBLIQUE
VERTICAL


BOULDER
JUNE 29, 1958
WASHINGTON
100 KM
0759
0800
1059
1100
1359
1400
1659
1700
5
10
15
20
25
MC
1
2
OBLIQUE
VERTICAL


BOULDER
JUNE 29— 30, 1958
WASHINGTON
100 KM
MC
1959
2259
0152
0459
2000
2300
0200
0500
OBLIQUE
VERTICAL



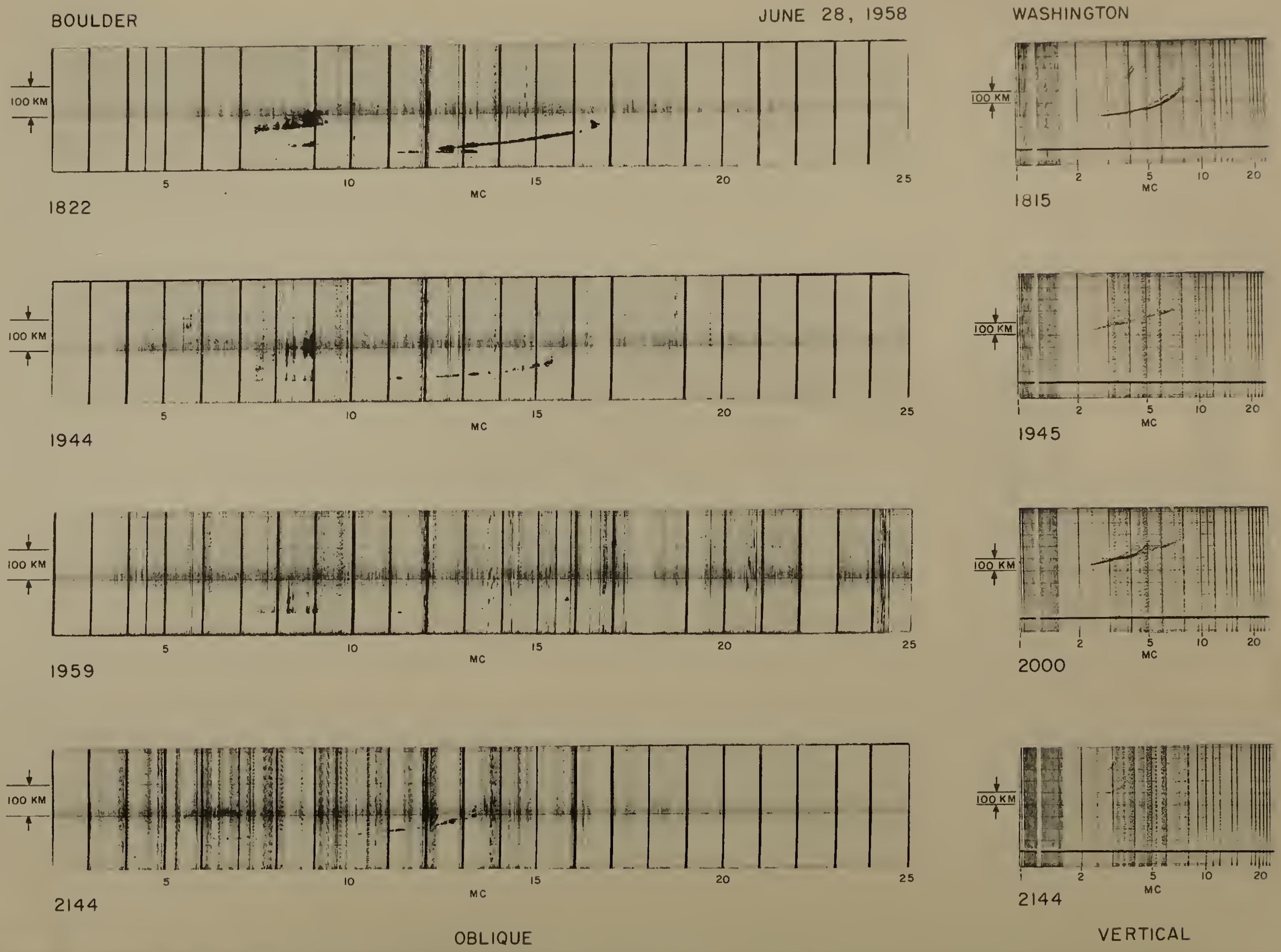
BOULDER
JUNE 30, 1958
WASHINGTON
100 KM
5
10
15
20
25
MC
0759
1059
1407
1559
1
2
5
10
20
MC
0800
1100
1400
1600
OBLIQUE
VERTICAL

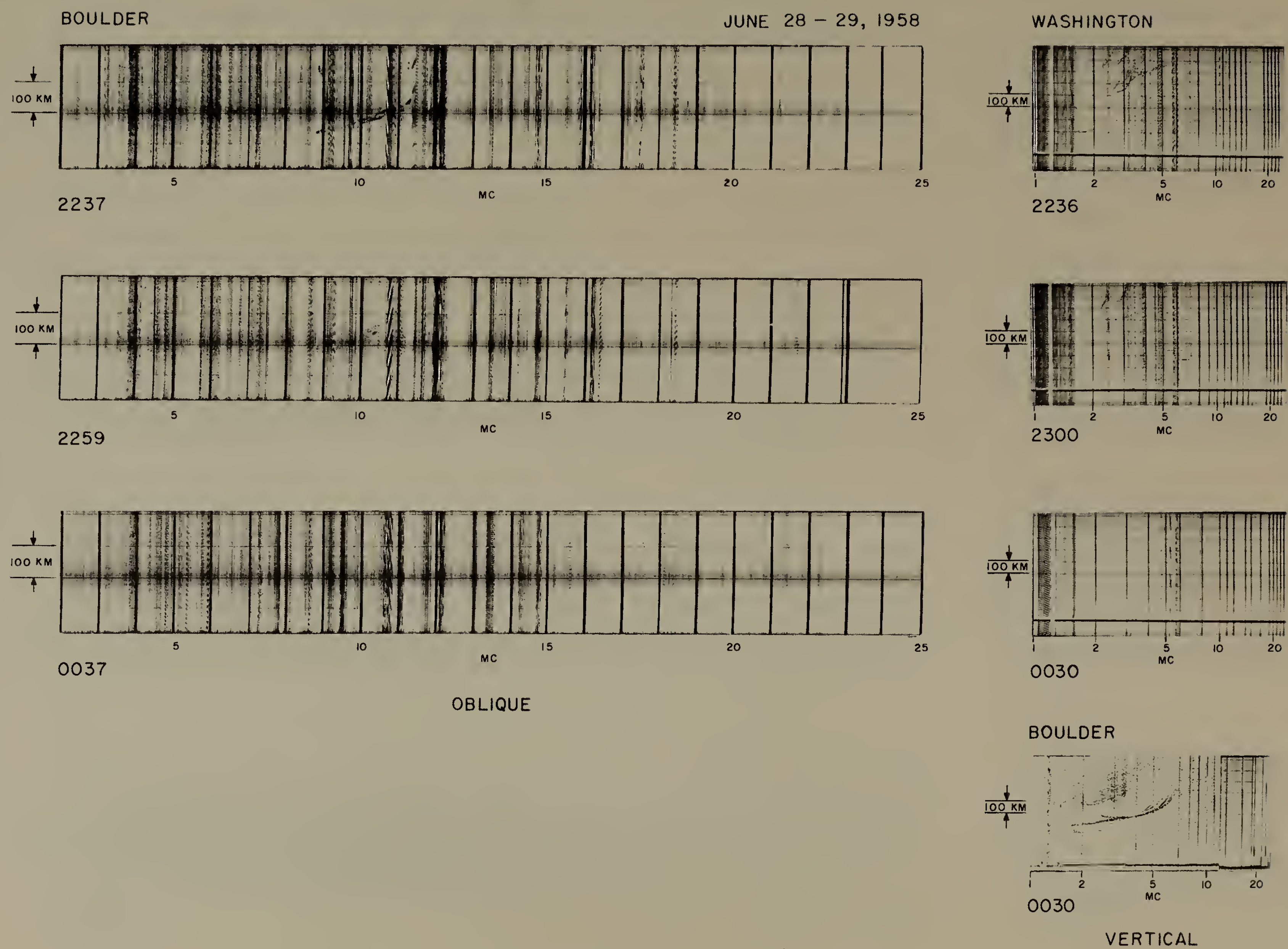
III-1B

Sterling-Boulder
(Experimental)

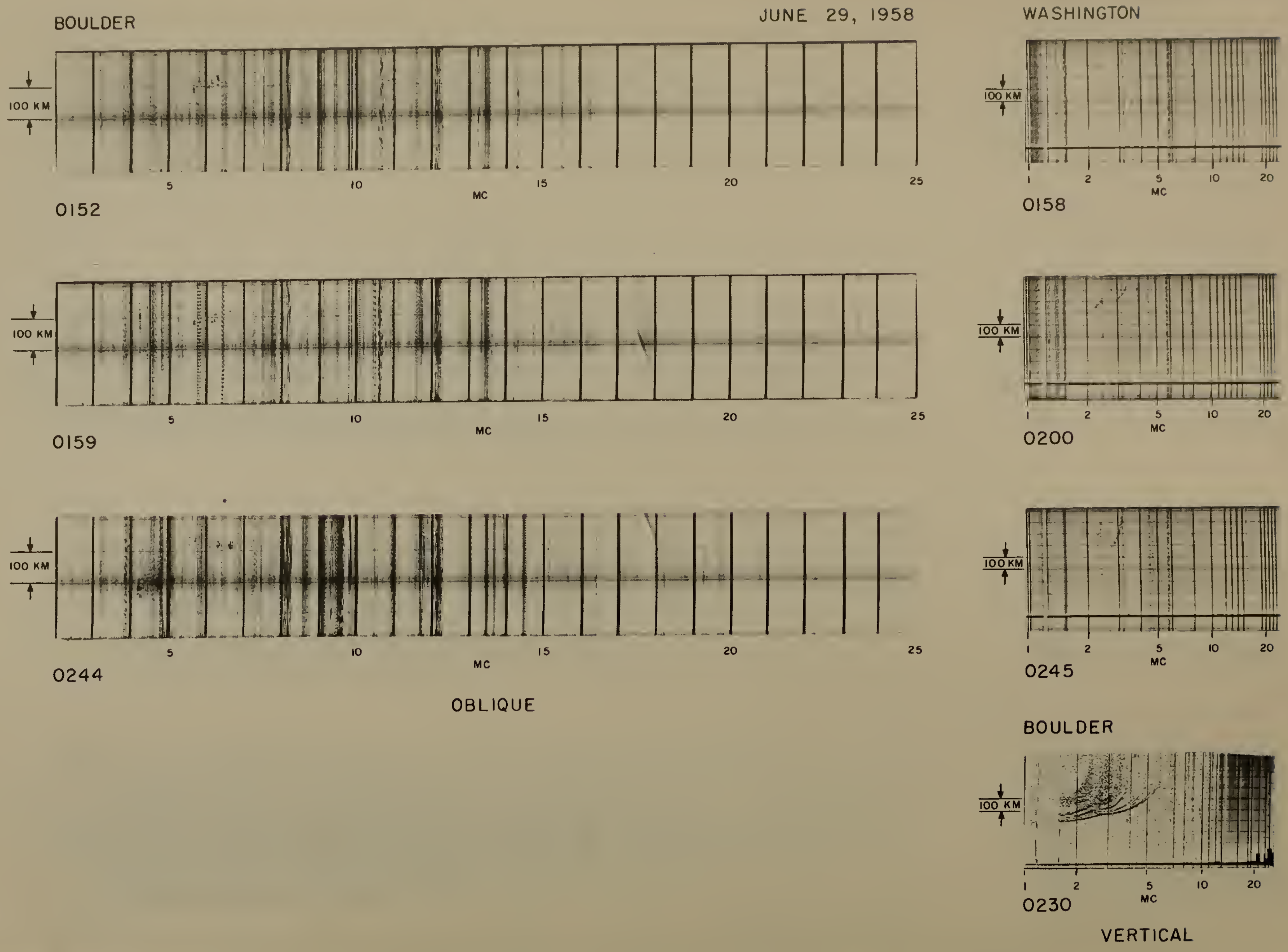
Detailed Sequence During Magnetic Storm

June 28-29, 1958

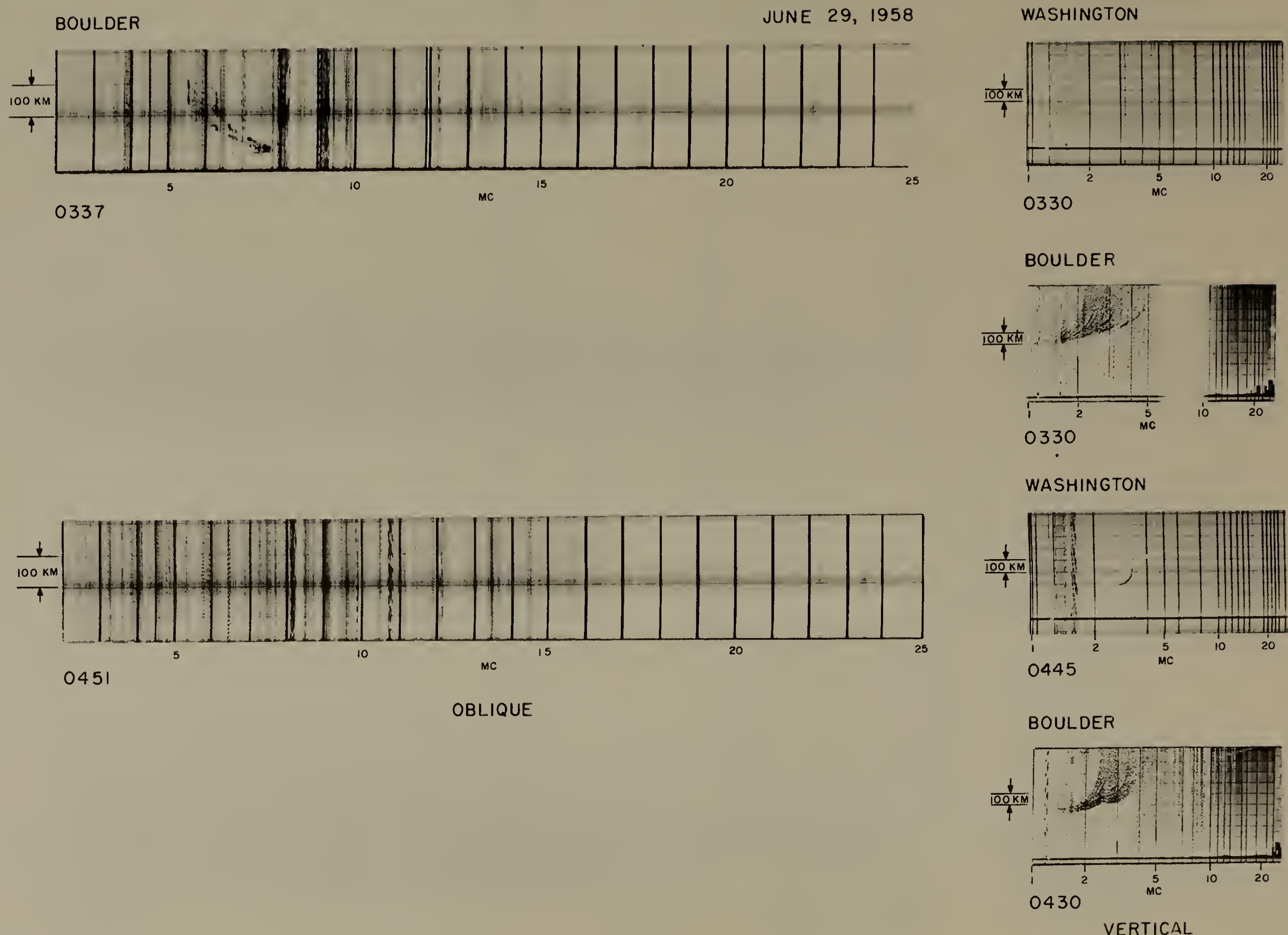

BOULDER
JUNE 28, 1958
WASHINGTON
100 KM
5
10
15
20
25
MC
1822
1815
1944
1945
1959
2000
2144
2144
1
2
OBLIQUE
VERTICAL



BOULDER
JUNE 28 – 29, 1958
WASHINGTON
100 KM
5
10
15
20
25
MC
2237
1
2
5
10
20
MC
2236
2259
2300
0037
0030
OBLIQUE
BOULDER
0030
VERTICAL

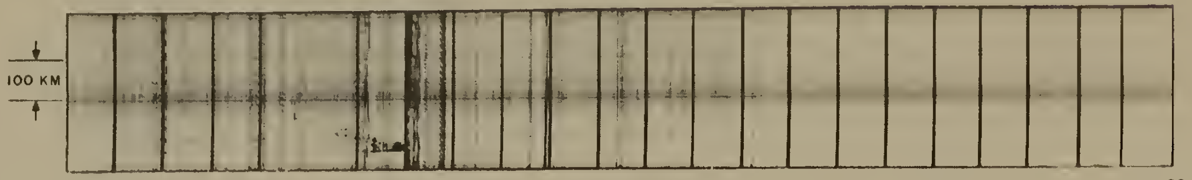


BOULDER
JUNE 29, 1958
100 KM
5
10
15
20
25
MC
0152
0159
0244
OBLIQUE
WASHINGTON
1
2
5
10
20
MC
0158
0200
0245
BOULDER
0230
VERTICAL

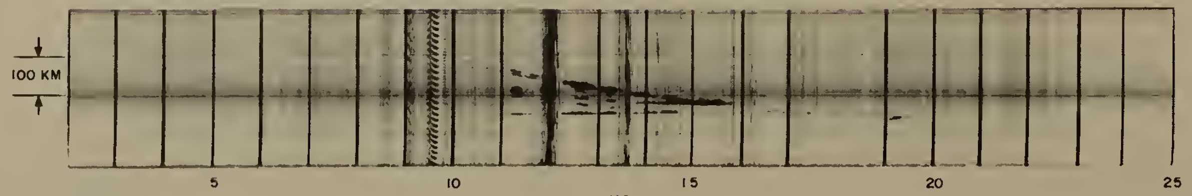

JUNE 29, 1958
BOULDER
100 KM
5
10
15
20
25
MC
0337
WASHINGTON
100 KM
1
2
5
10
20
MC
0330
BOULDER
100 KM
1
2
5
10
20
MC
0330
100 KM
5
10
15
20
25
MC
0451
OBLIQUE
WASHINGTON
100 KM
1
2
5
10
20
MC
0445
BOULDER
100 KM
1
2
5
10
20
MC
0430
VERTICAL

BOULDER

JUNE 29, 1958



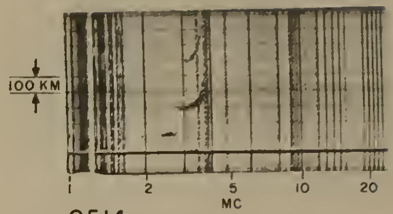
0514



0759

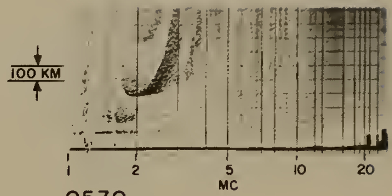
OBLIQUE

WASHINGTON



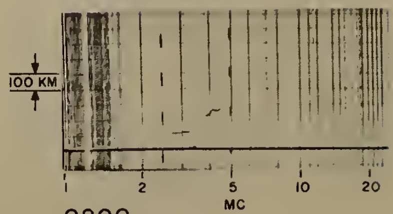
0514

BOULDER



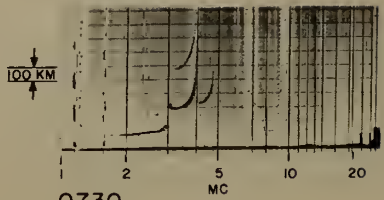
0530

WASHINGTON



0800

BOULDER



0730

VERTICAL

Sterling-Boulder
(Experimental)

Morning and Afternoon Sequences

June 20, 1958

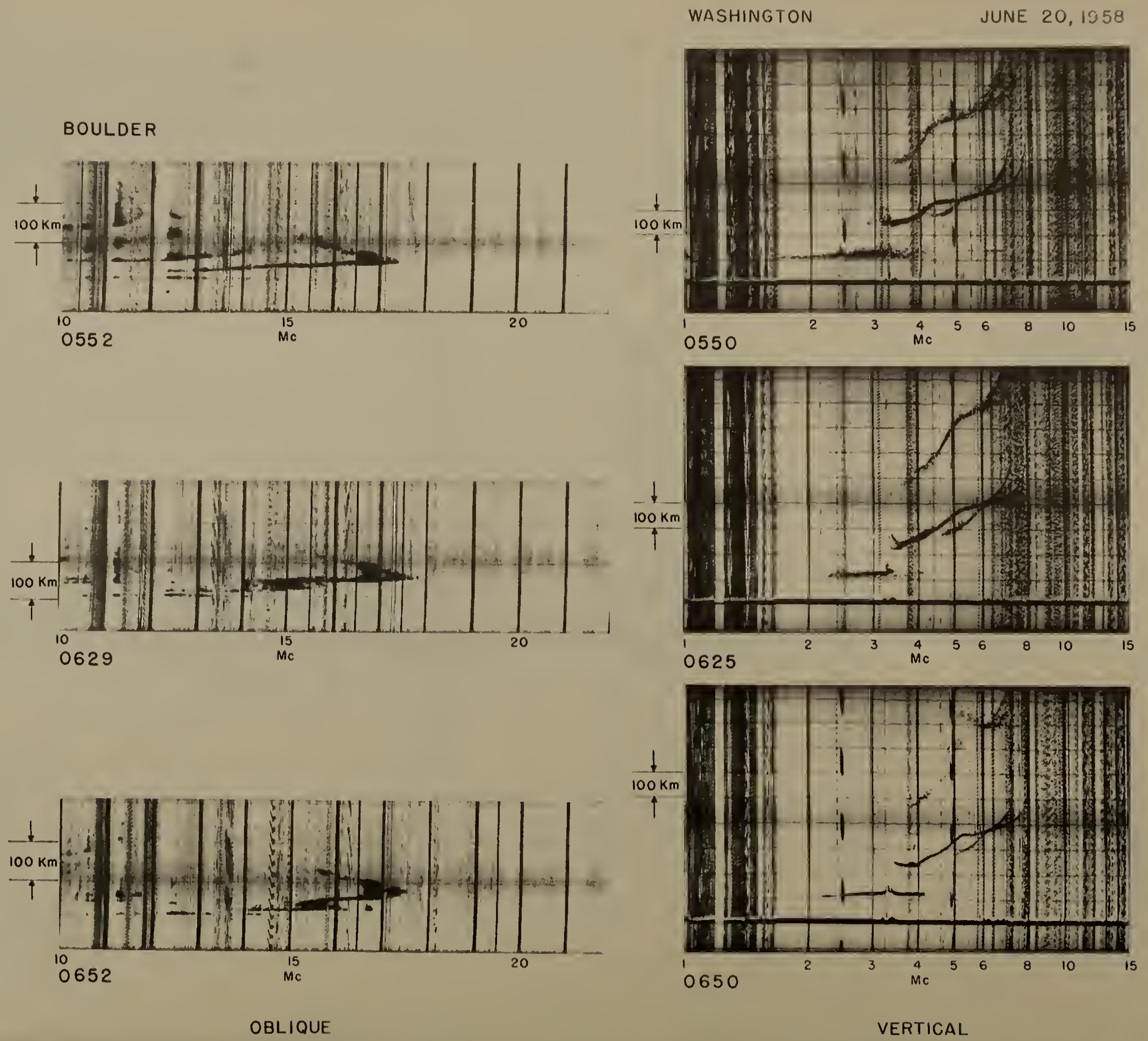
Unusual morning sequence showing the development of an F1 layer and then an F2 layer.

June 9, 1958

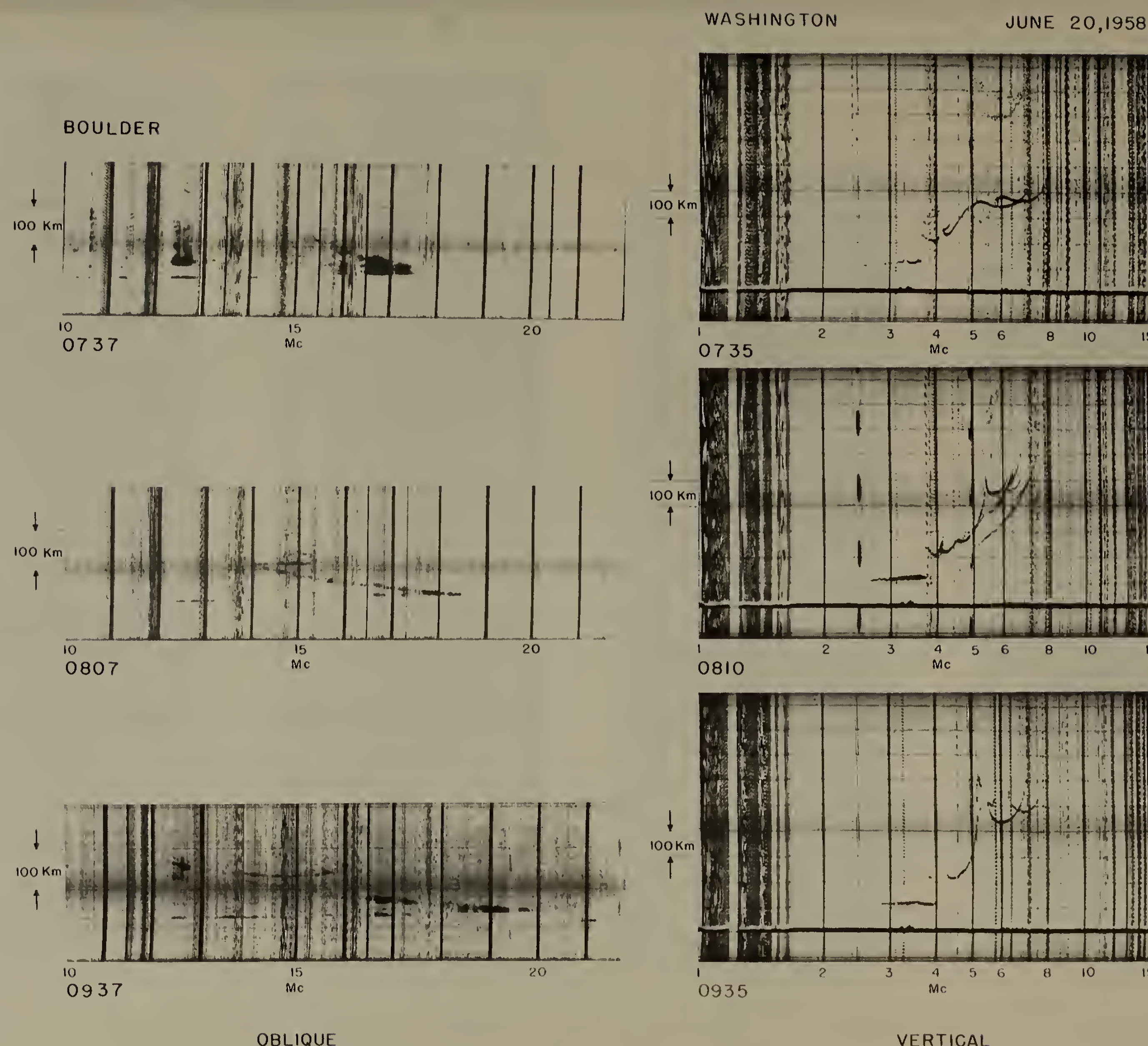
Normal afternoon sequence. The trace of a possible off-path signal may be seen from 1813 to 1835 CST.

August 6, 1958

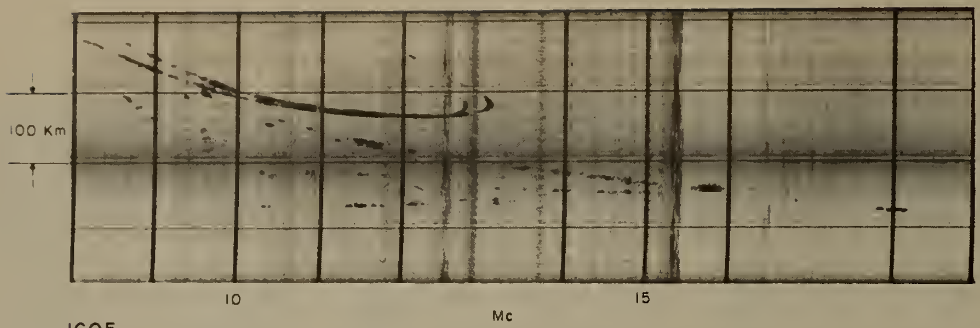
Normal afternoon sequence. A disturbance in the F2 layer can be seen on the oblique- and vertical-incidence ionograms at 1454 CST.



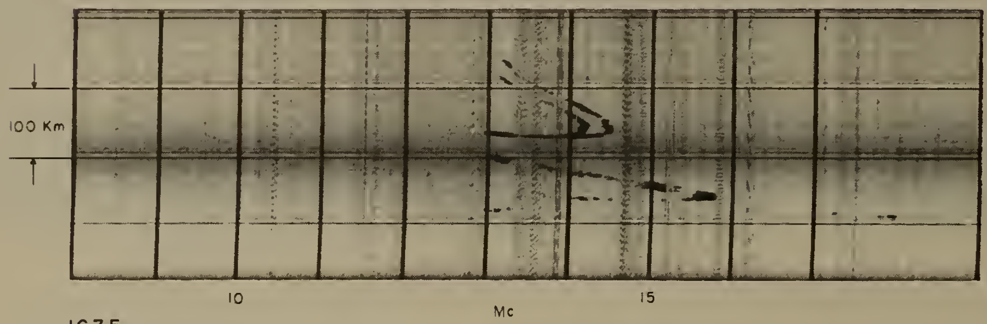
WASHINGTON
JUNE 20, 1958
BOULDER
100 Km
10
15
20
Mc
0552
0629
0652
1
2
3
4
5
6
8
10
15
0550
0625
0650
OBLIQUE
VERTICAL


BOULDER
WASHINGTON
JUNE 20,1958
100 Km
10
15
20
Mc
0737
0807
0937
1
2
3
4
5
6
8
10
15
0735
0810
0935
OBLIQUE
VERTICAL

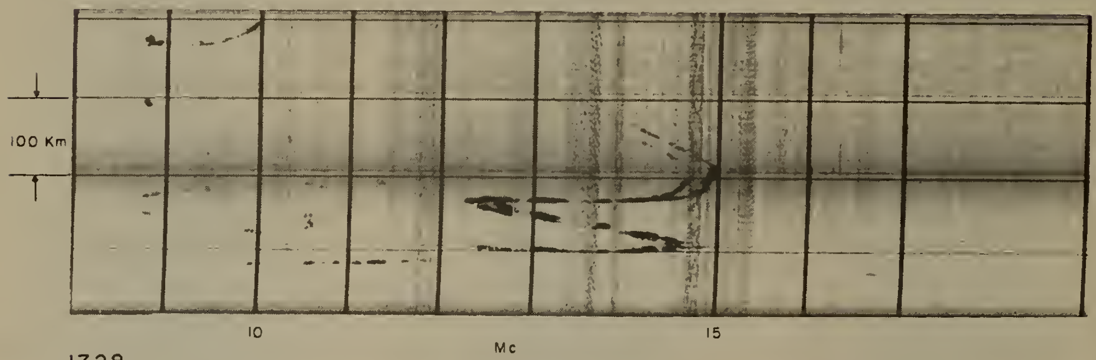
BOULDER JUNE 9,1958



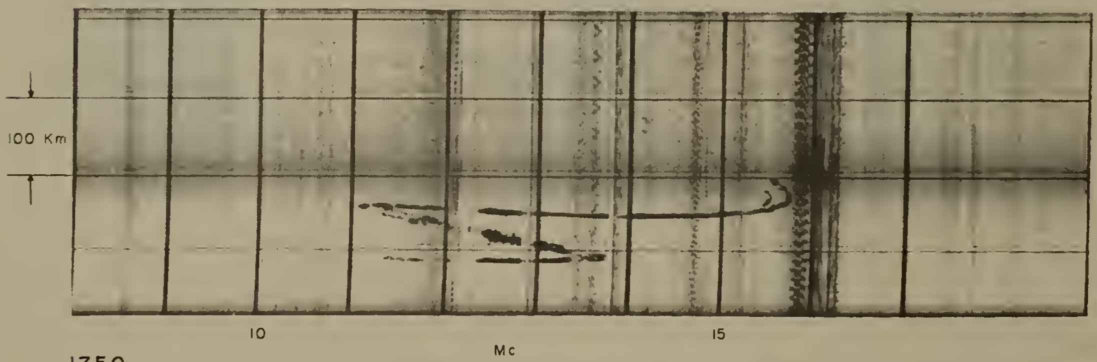
1605



1635

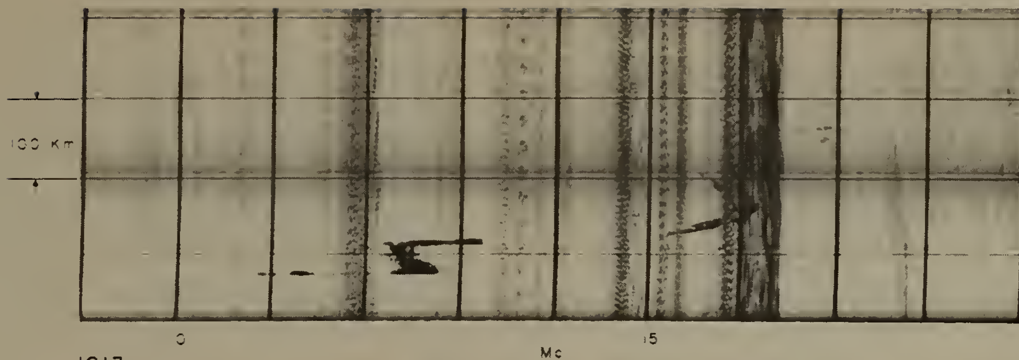


1728

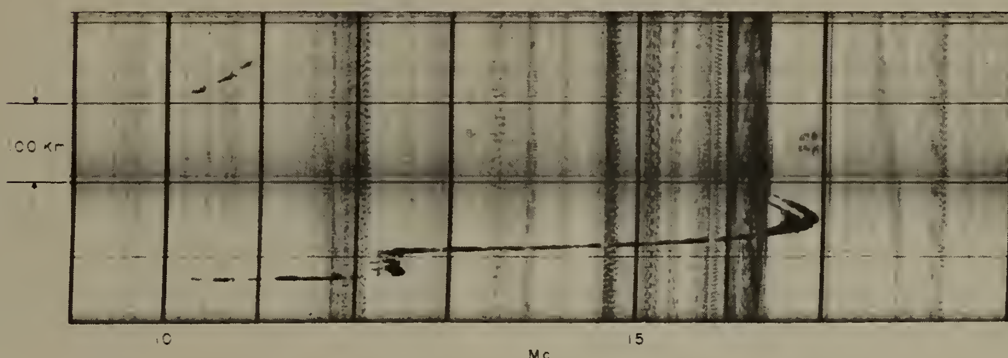


1750

BOULDER JUNE 9, 1958



1813



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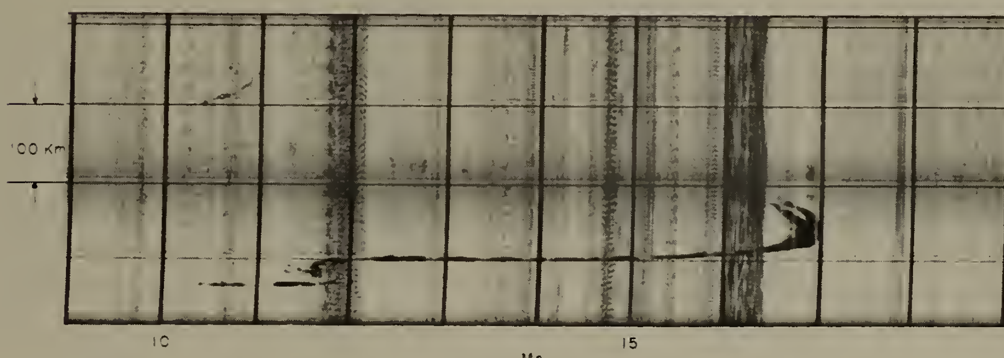
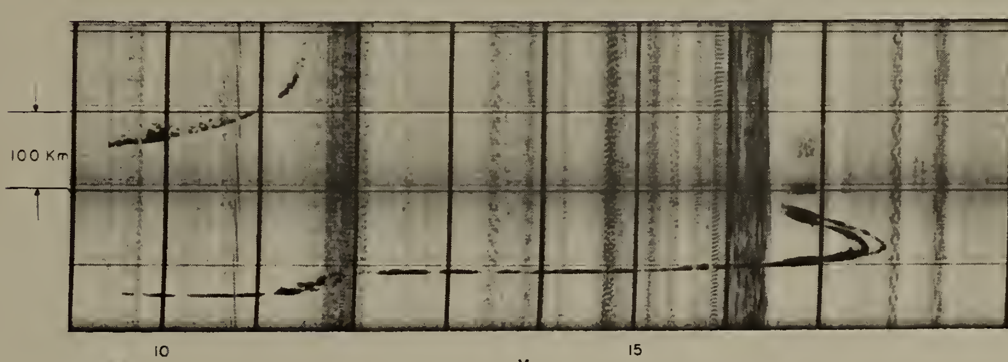
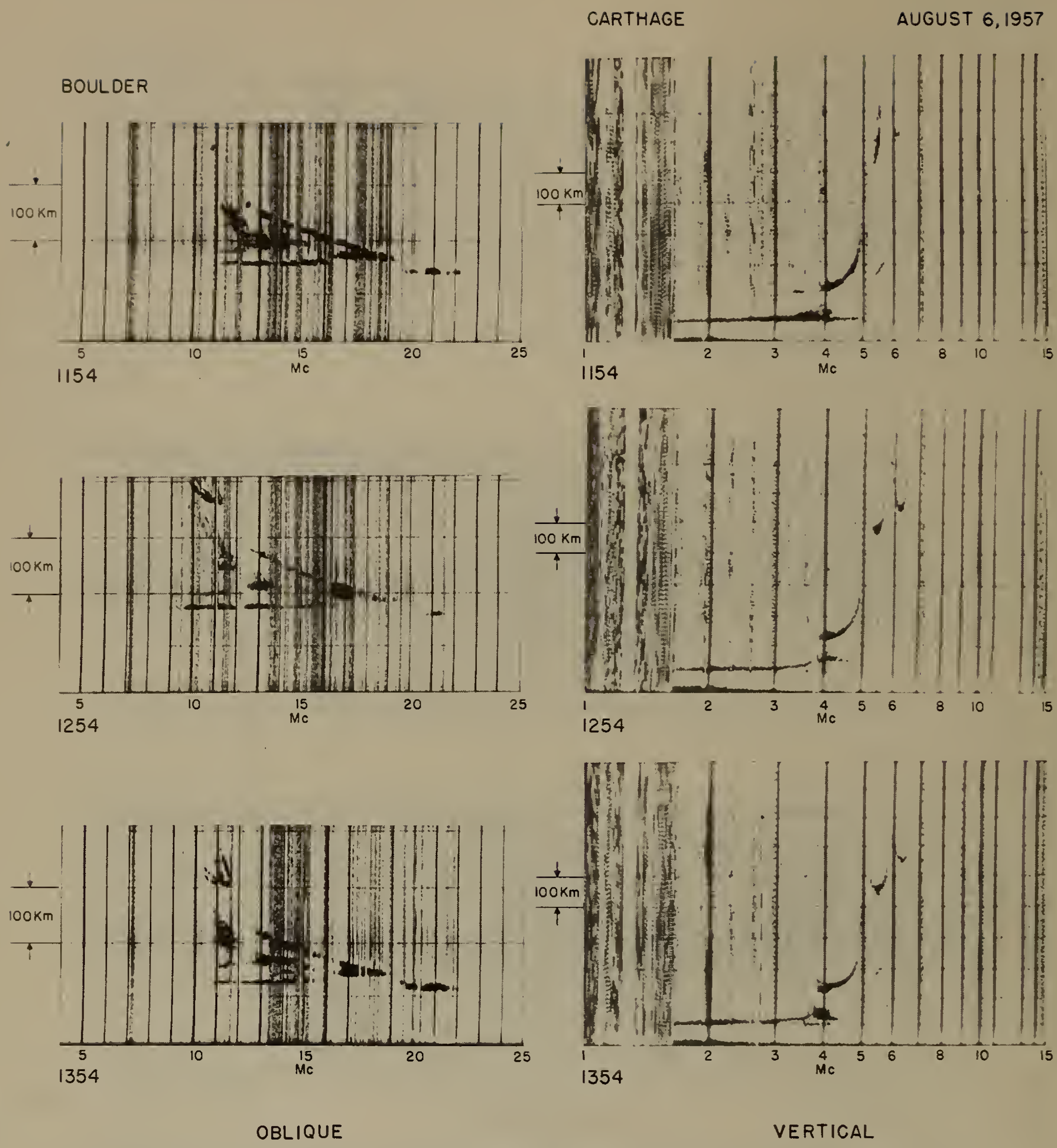
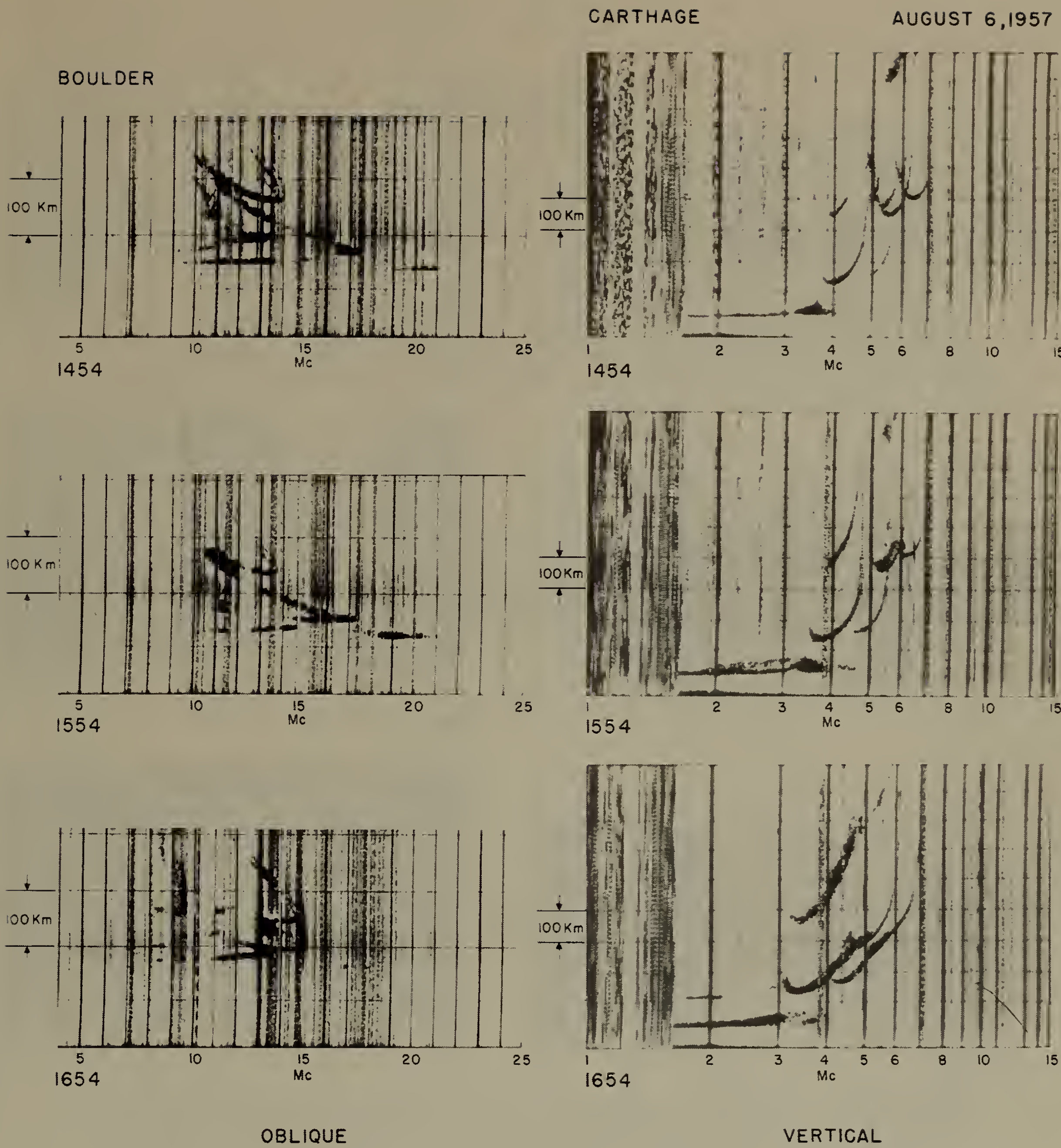


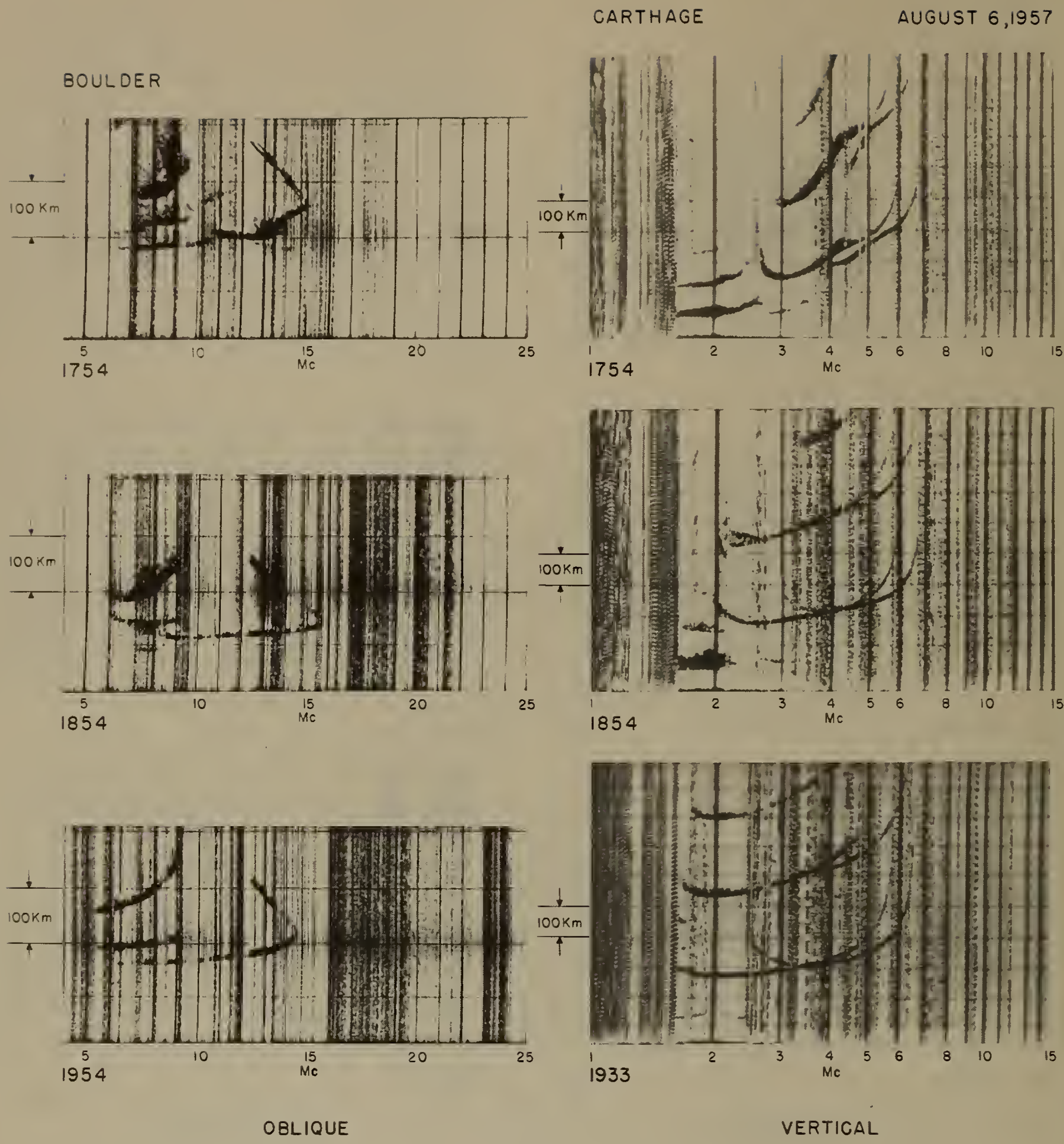
1828



1835


CARTHAGE
AUGUST 6, 1957
BOULDER
100 Km
5
10
15
20
25
Mc
1154
1254
1354
1
2
3
4
5
6
8
10
15
OBLIQUE
VERTICAL


BOULDER
CARTHAGE
AUGUST 6,1957
100 Km
5
10
15
20
25
Mc
1454
1554
1654
1
2
3
4
5
6
8
10
15
OBLIQUE
VERTICAL



BOULDER
CARTHAGE
AUGUST 6,1957
100 Km
1754
1854
1954
1933
5 10 15 20 25
1 2 3 4 5 6 8 10 15
Mc
OBLIQUE
VERTICAL

Sterling-Boulder
(Experimental)

"Inner"* and "Outer" Nose

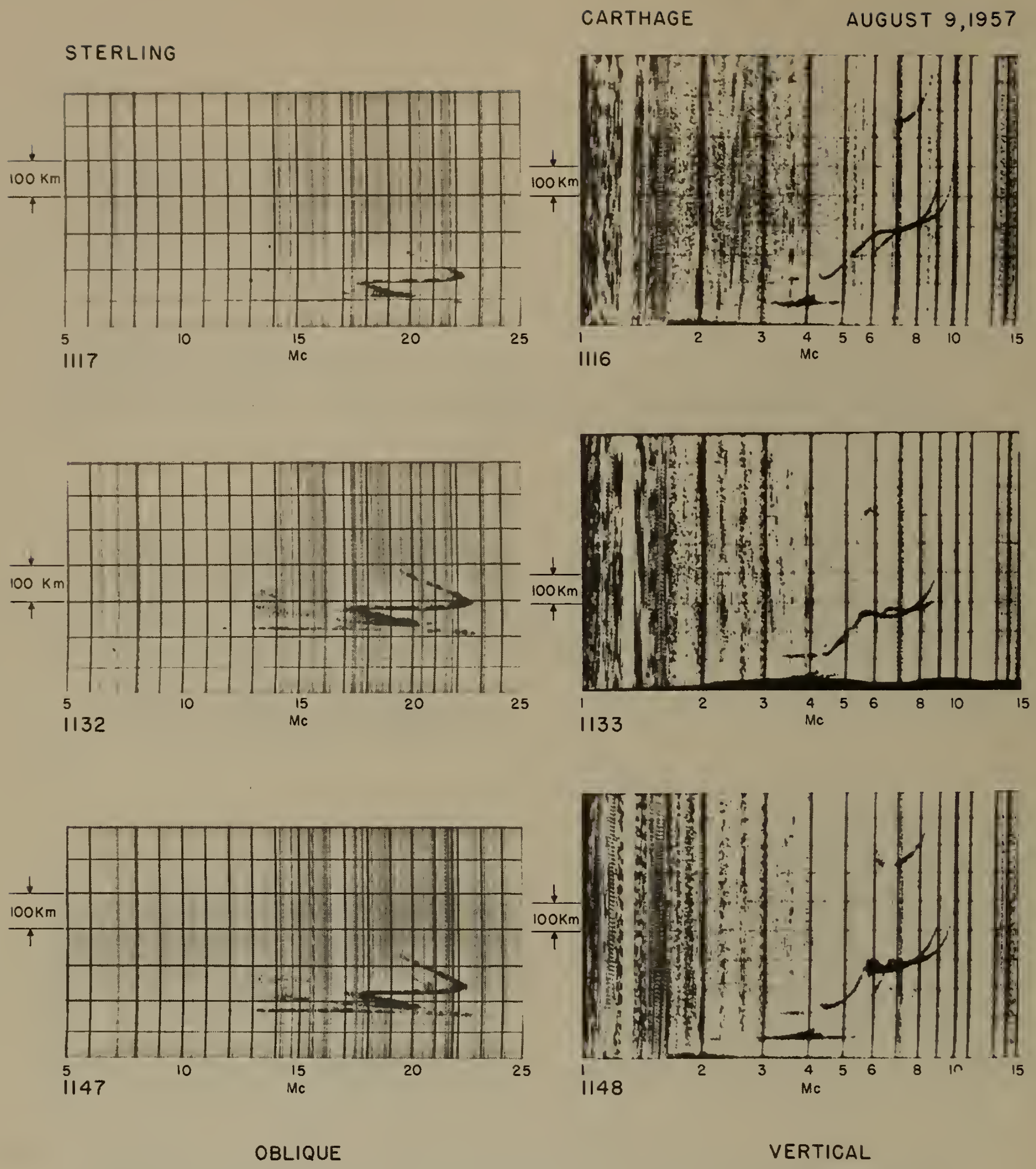
August 9, 1957
August 23, 1957

Sequences showing development of "inner" nose on oblique-incidence ionograms and simultaneous midpoint vertical-incidence disturbances.

June 19, 1958

Sequence showing development of "outer" nose on oblique-incidence ionograms and blanketing by Es on end-point vertical-incidence ionograms.

*Occasionally, as shown in the following records, in addition to the well defined "nose" representing the classical F2 MUF, a second nose appears at frequencies below (or above) the classical MUF. The additional nose, for the sake of brevity, is referred to as an "inner" (or "outer") nose.

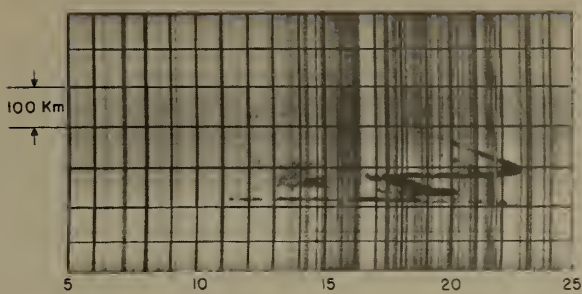


STERLING
CARTHAGE
AUGUST 9,1957
100 Km
1117
1116
1132
1133
1147
1148
Mc
5
10
15
20
25
1
2
3
4
5
6
8
10
15
OBLIQUE
VERTICAL

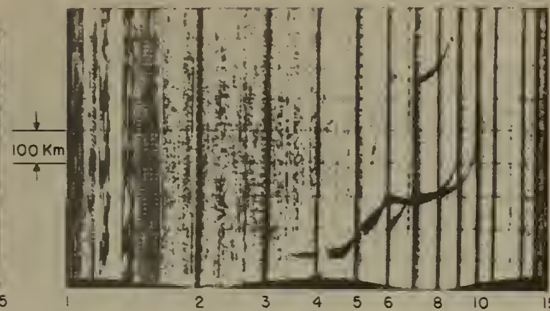
STERLING

CARTHAGE

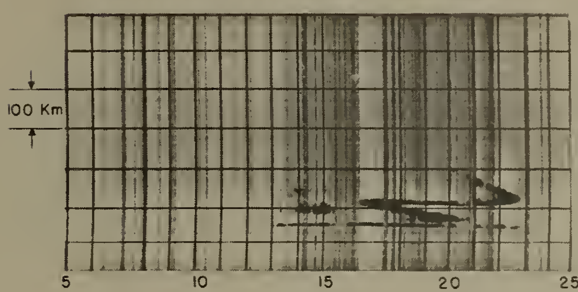
AUGUST 9,1957



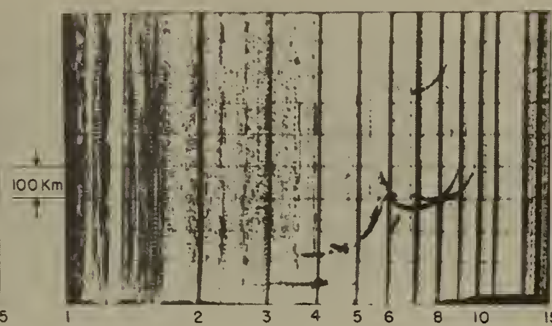
1202



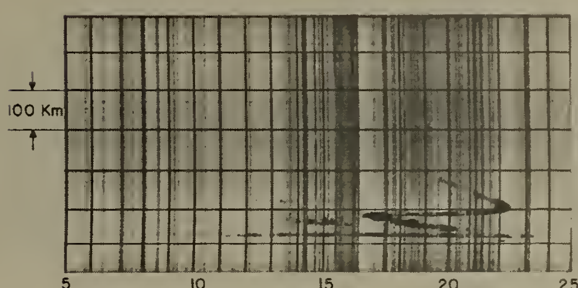
1201



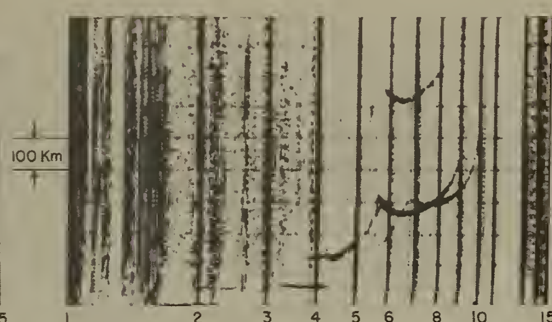
1217



1218



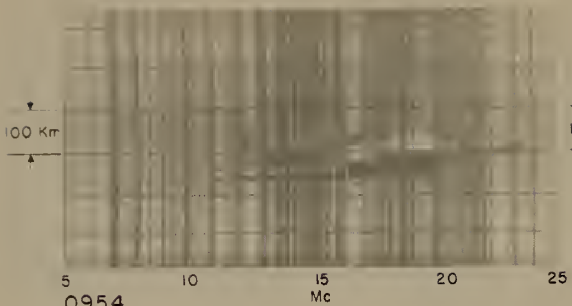
1232



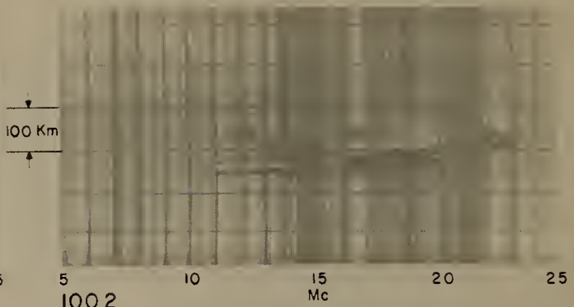
1233

OBLIQUE

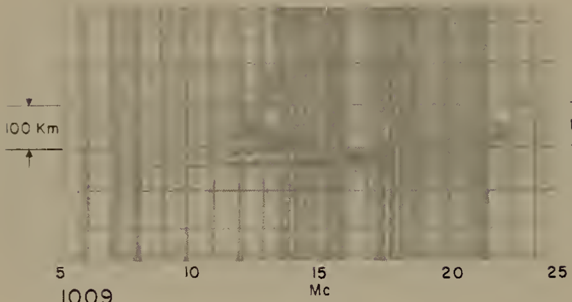
VERTICAL



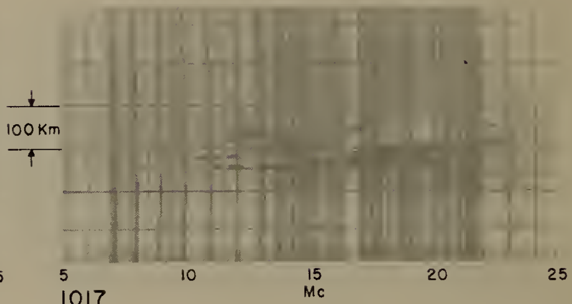
0954



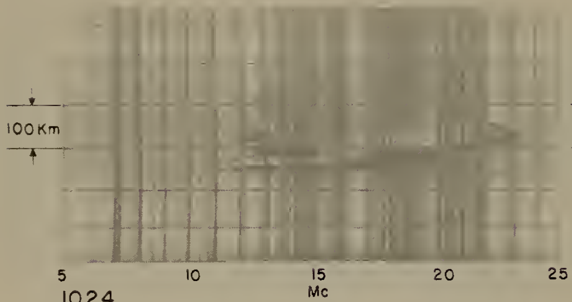
1002



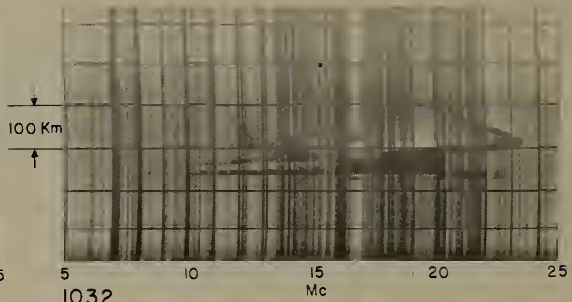
1009



1017



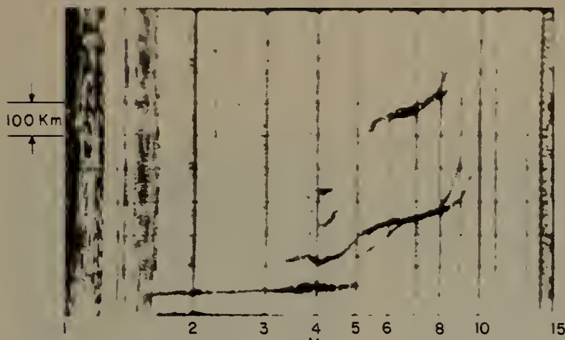
1024



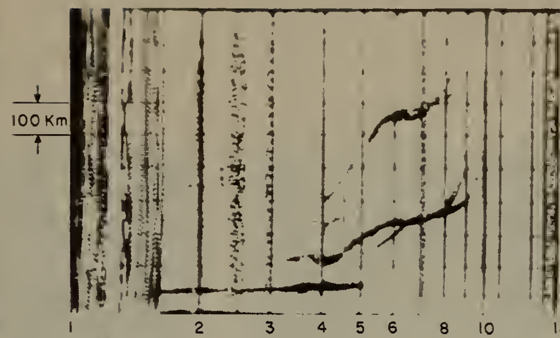
1032

OBLIQUE

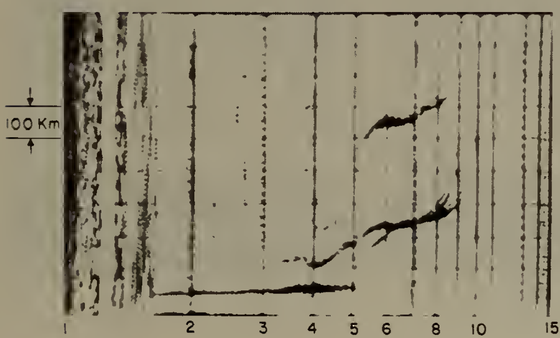
CARTHAGE AUGUST 23, 1957



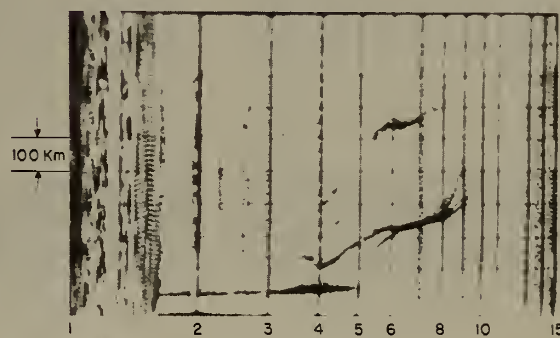
0948



0951



0954



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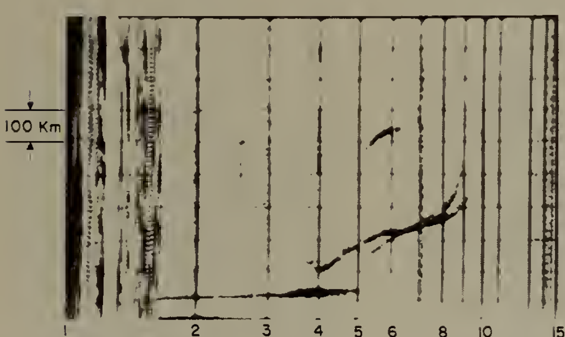
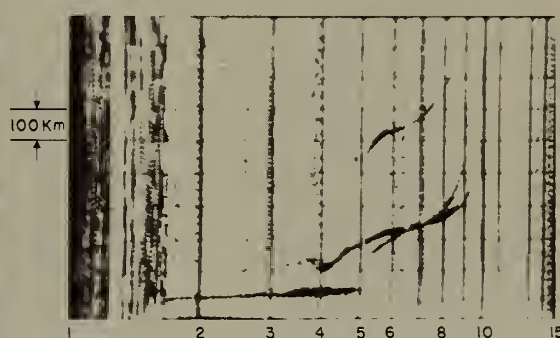
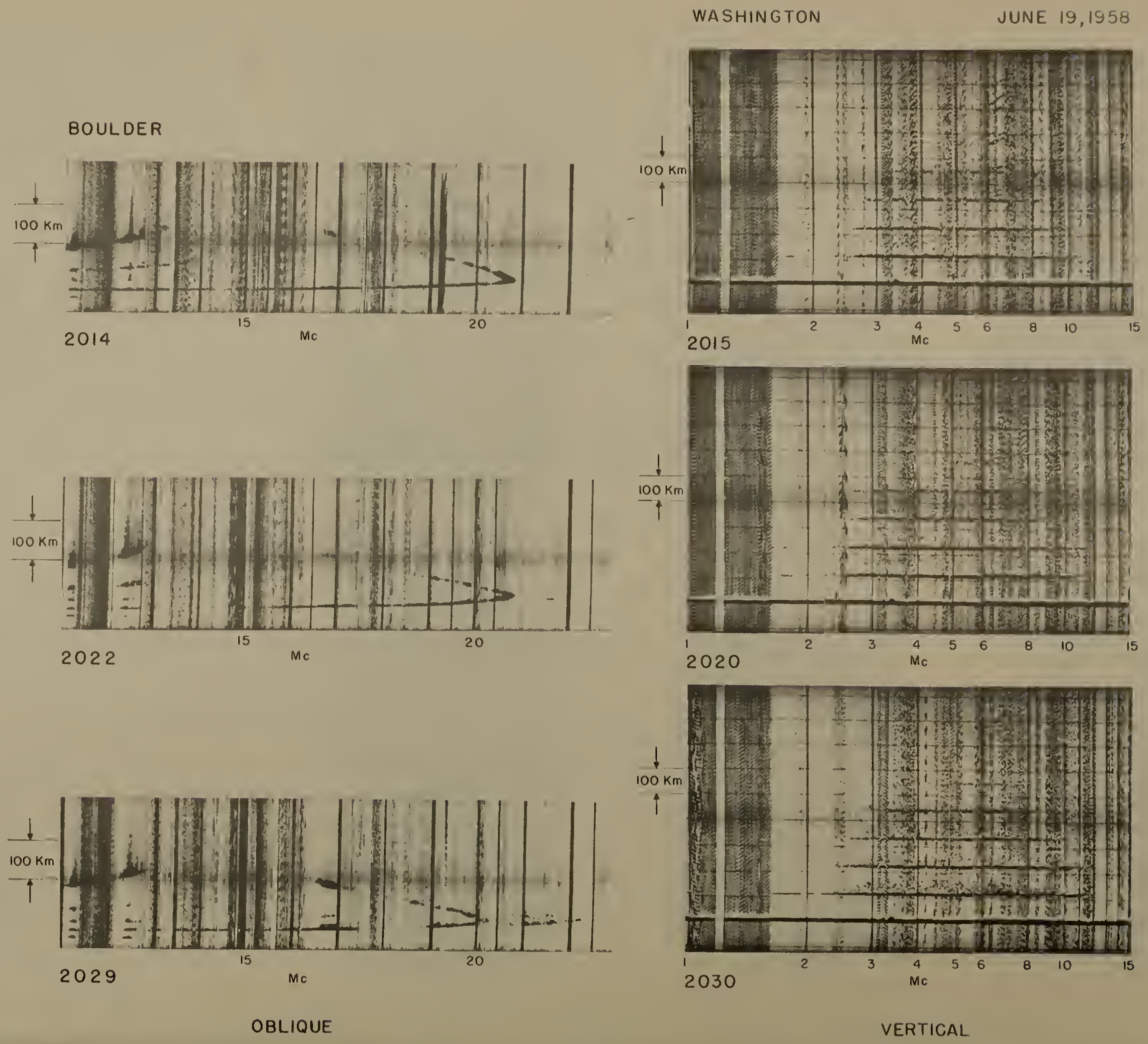


0959

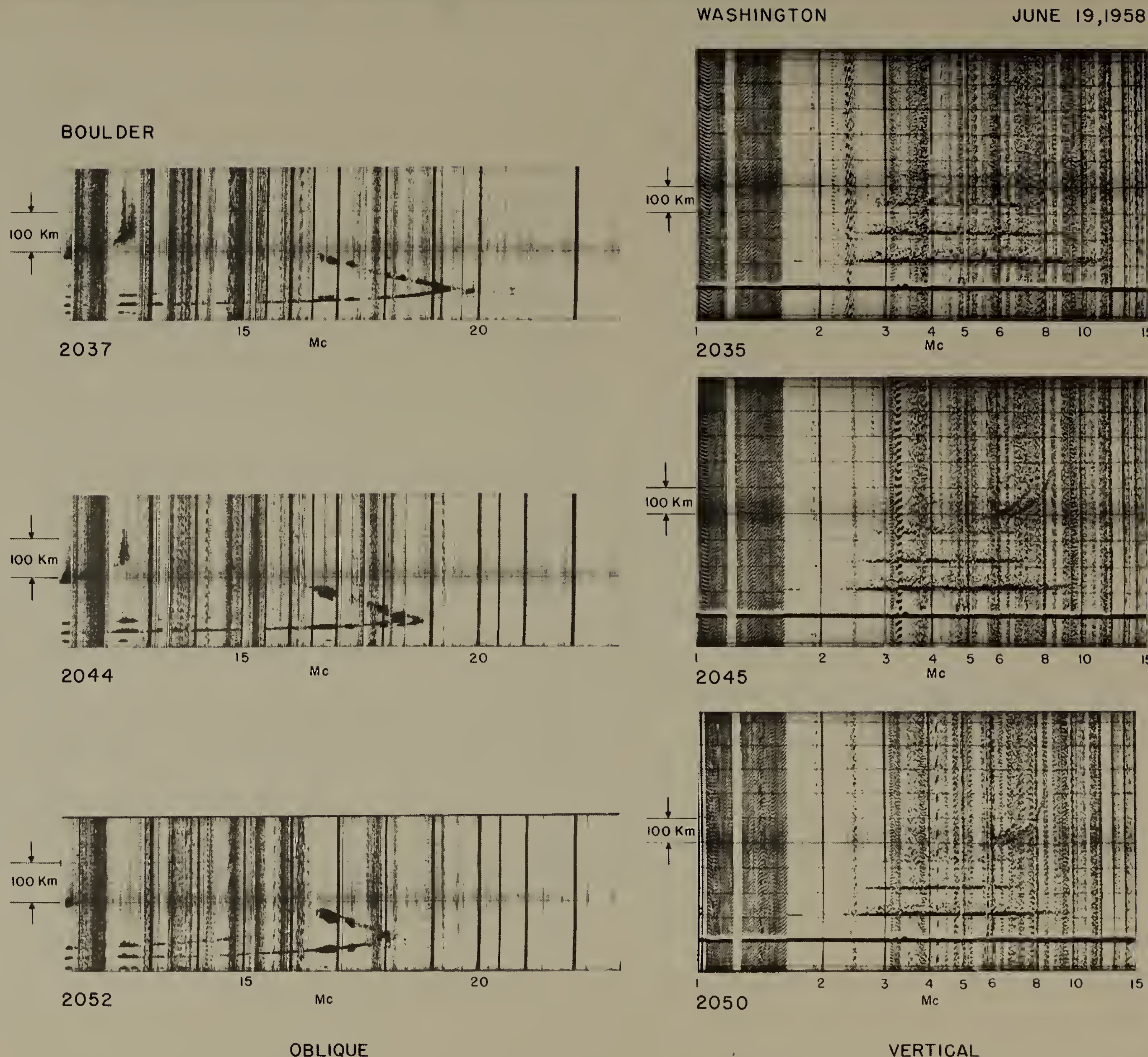


1000

VERTICAL



BOULDER
WASHINGTON
JUNE 19, 1958
100 Km
2014
15
20
Mc
2015
1
2
3
4
5
6
8
10
15
Mc
2022
2020
2029
2030
OBLIQUE
VERTICAL



WASHINGTON
JUNE 19,1958
BOULDER
100 Km
2037
15
Mc
20
2044
2052
2035
2045
2050
1
2
3
4
5
6
8
10
15
OBLIQUE
VERTICAL

Sterling-Boulder
(Experimental)

"Disturbed F2 Nose"

April 30, 1957

Some spread can be seen on midpoint vertical-incidence ionograms at time of "disturbed nose" on oblique-incidence ionograms.

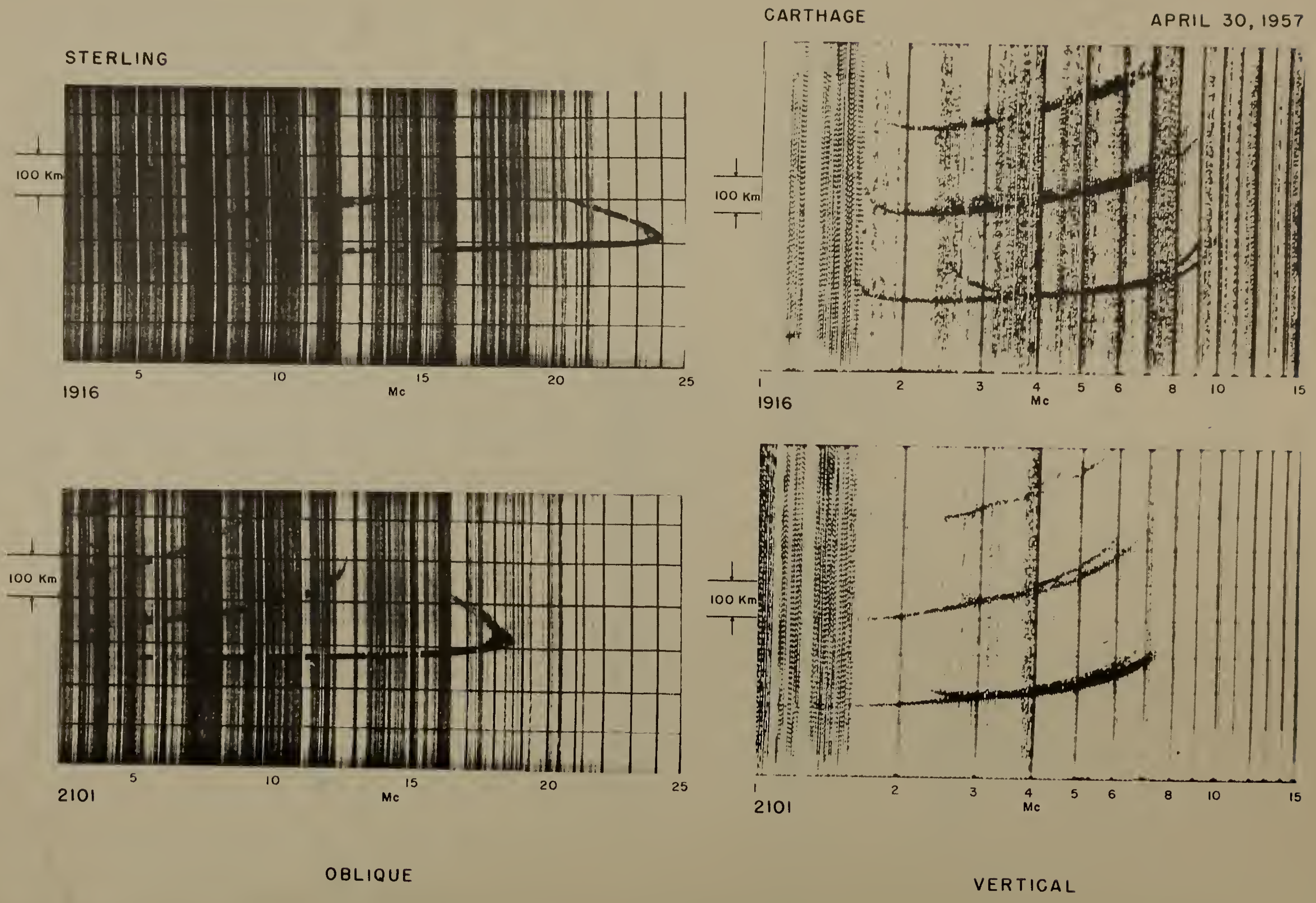
April 20, 1958

May 12, 1958

Sequences of "disturbed-nose" oblique-incidence ionograms.

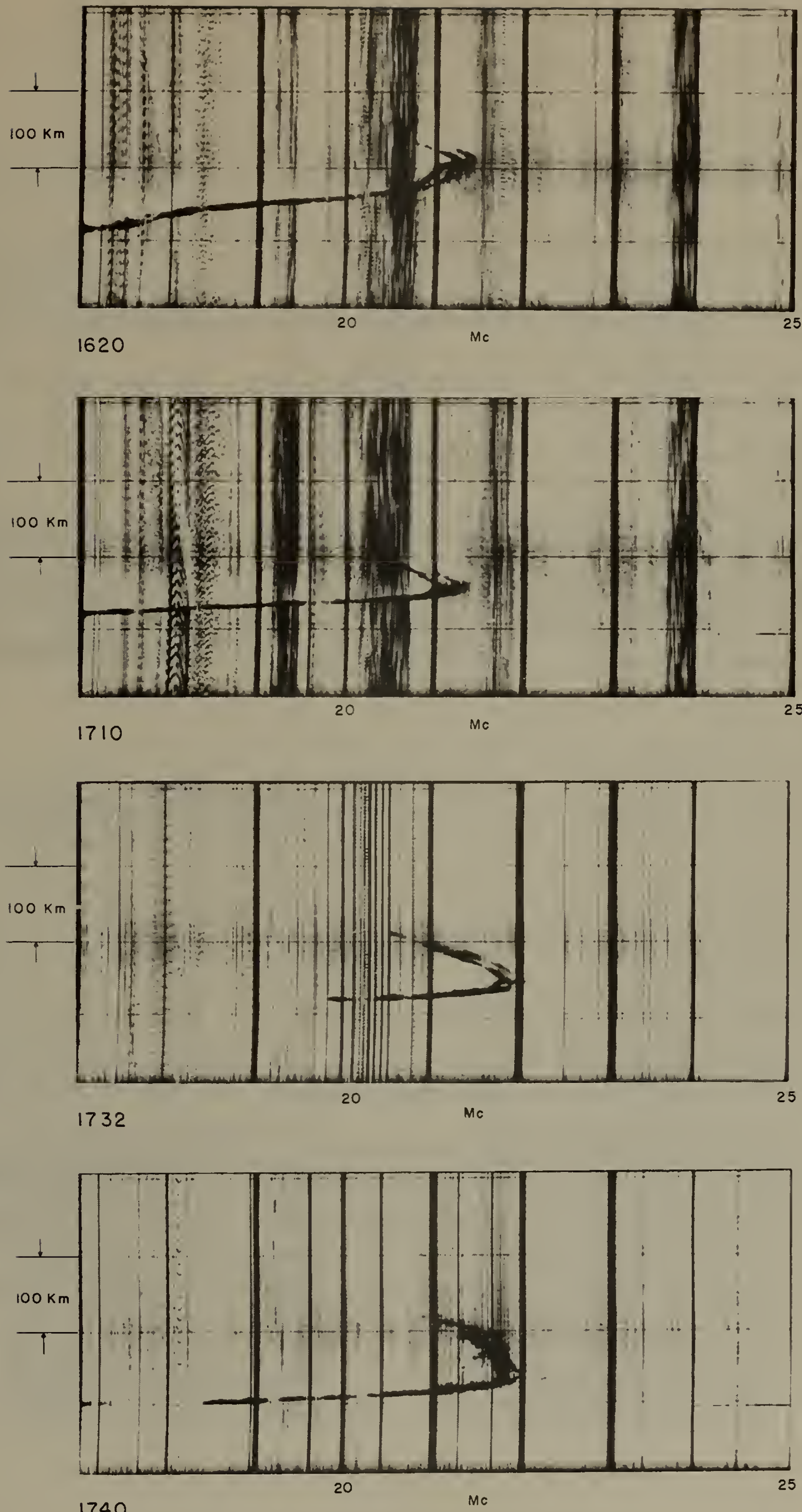
June 24, 1958

Spread nose on oblique-incidence ionogram and spread F on end-point vertical-incidence ionograms.

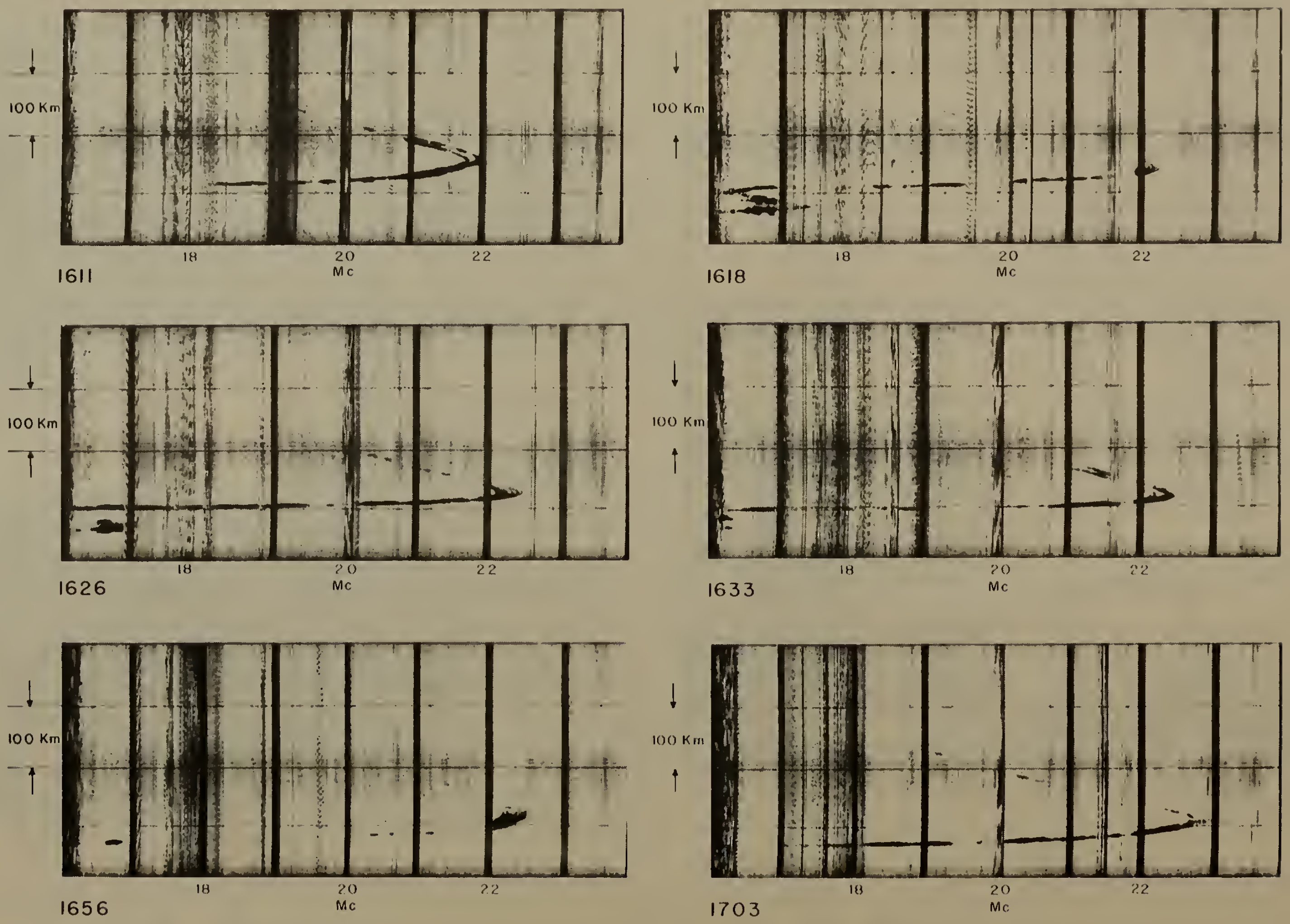


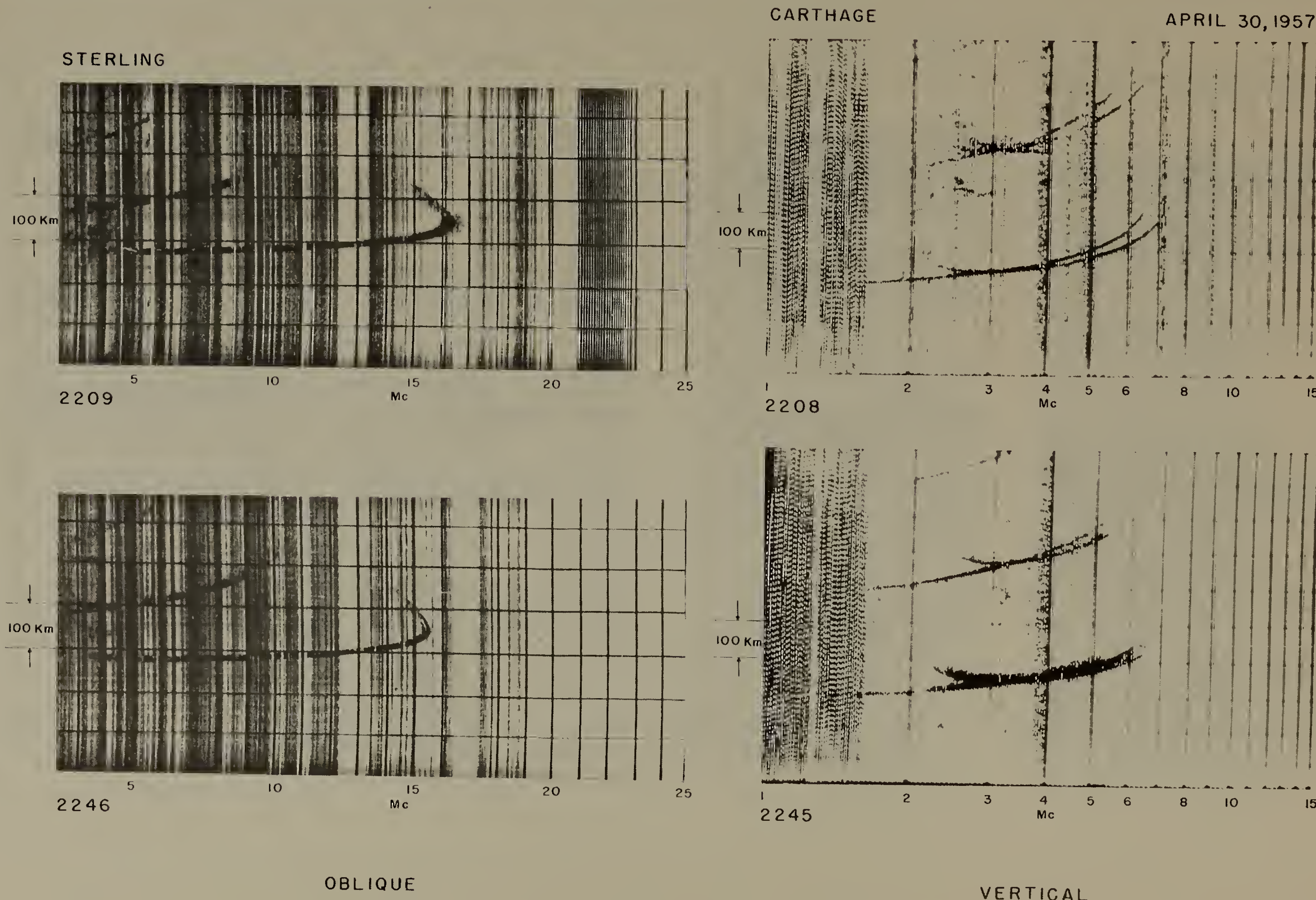
STERLING
CARTHAGE
APRIL 30, 1957
100 Km
1916
2101
5
10
15
20
25
Mc
1
2
3
4
5
6
8
10
15
OBLIQUE
VERTICAL

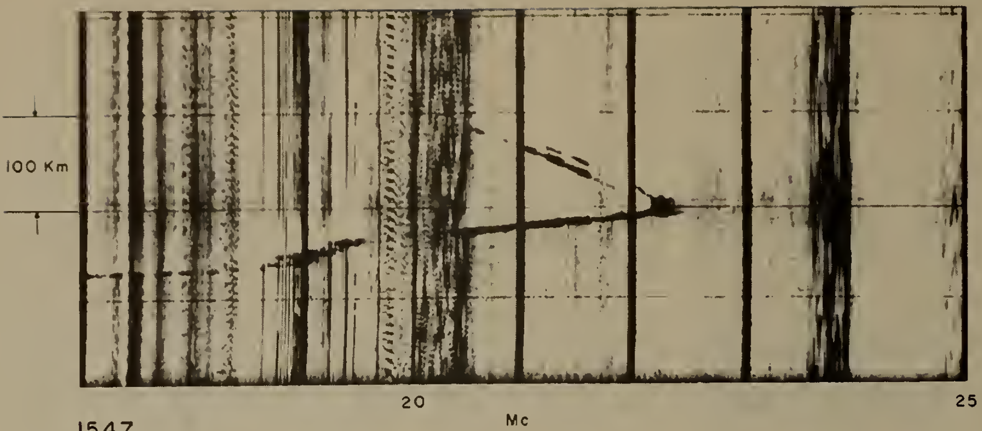
BOULDER APRIL 20, 1958



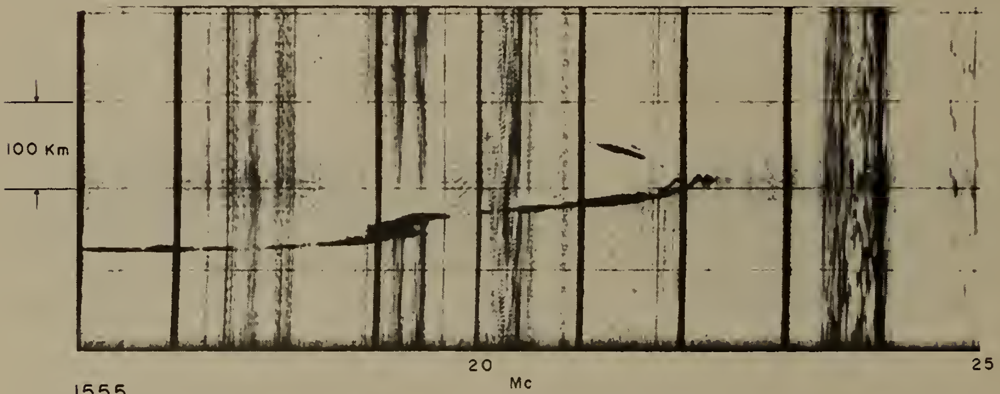
BOULDER MAY 12, 1958



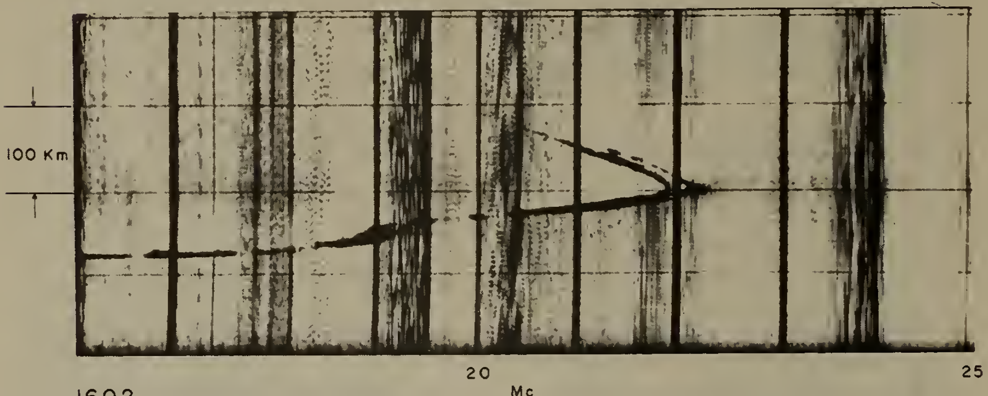

STERLING
CARTHAGE
APRIL 30, 1957
100 Km
5
10
15
20
25
Mc
2209
1
2
3
4
5
6
8
10
15
Mc
2208
2246
2245
OBLIQUE
VERTICAL



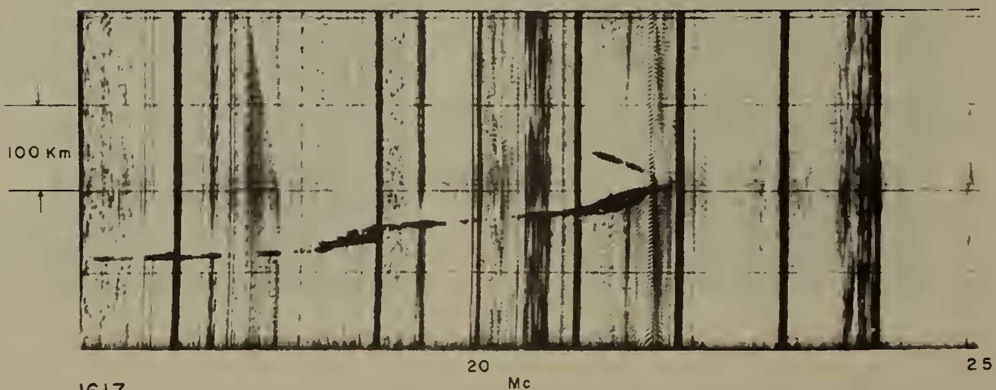
1547



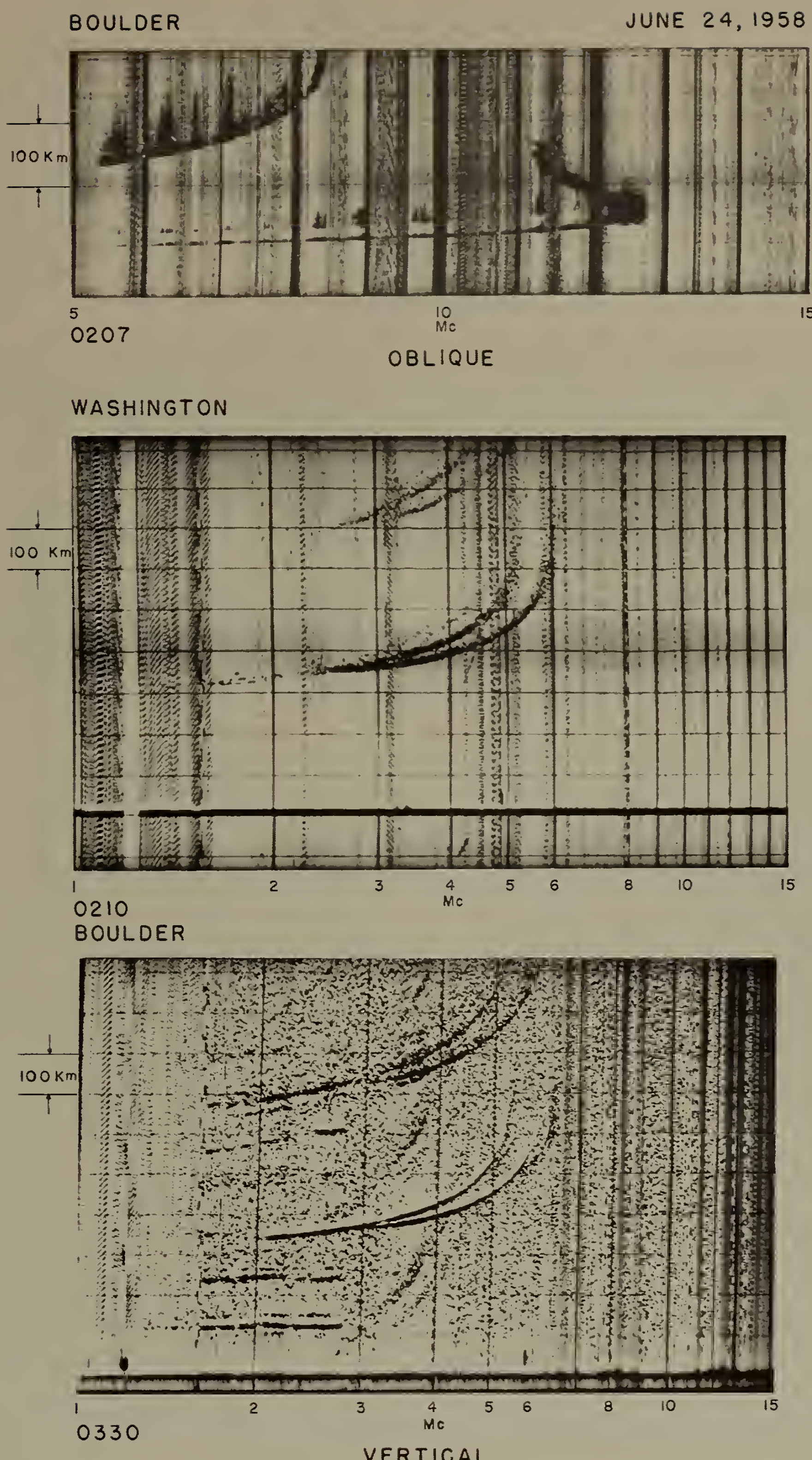
1555



1602



1617


BOULDER
JUNE 24, 1958
100 Km
5
10
Mc
15
0207
OBLIQUE
WASHINGTON
100 Km
1
2
3
4
5
6
8
10
15
Mc
0210
BOULDER
100 Km
1
2
3
4
5
6
8
10
15
Mc
0330
VERTICAL

Sterling-Boulder
(Experimental)

Disturbed Conditions

February 5, 1957

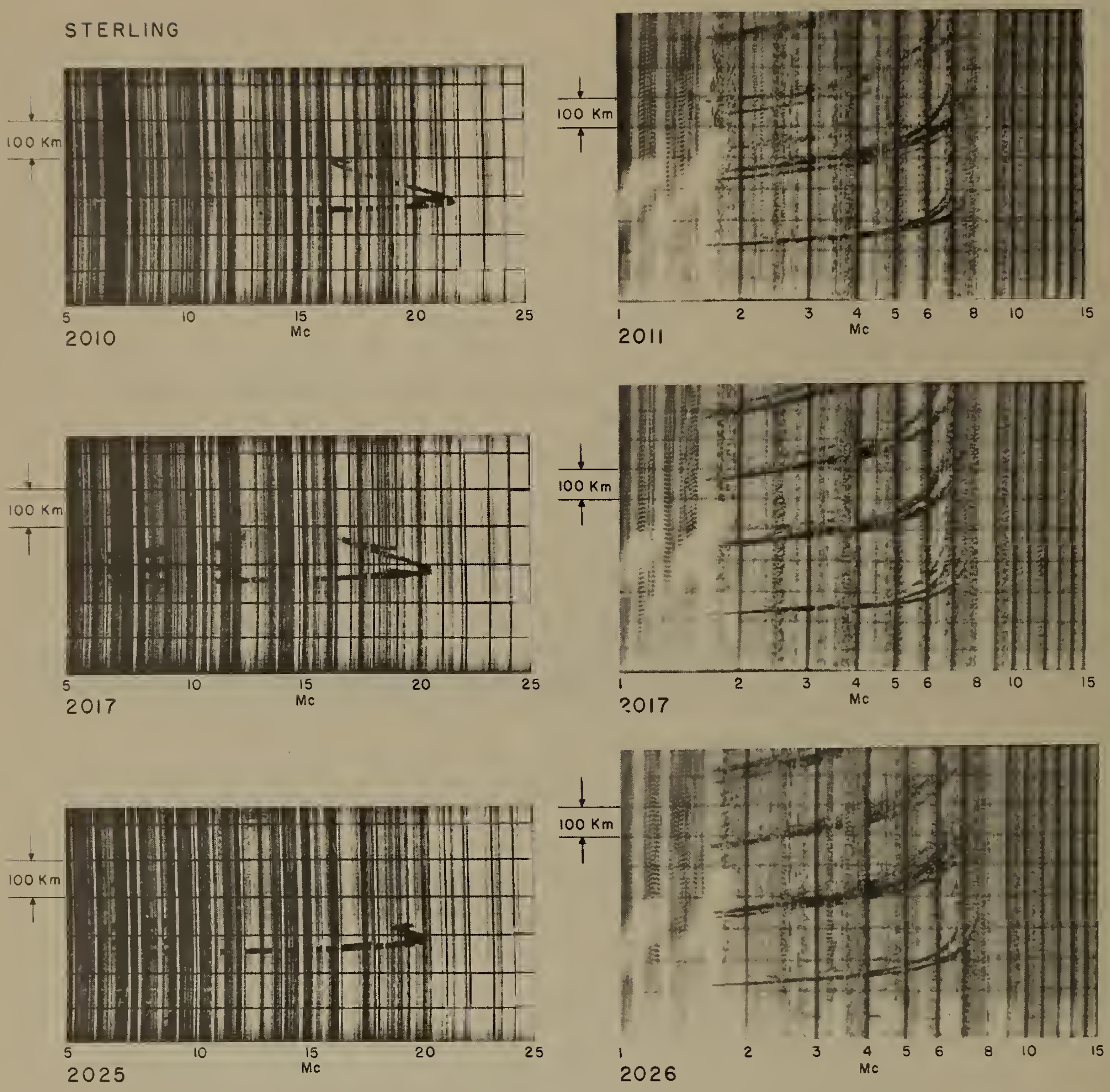
Sequence showing traveling disturbance in oblique- and vertical-incidence ionograms.

June 9, 1958

Disturbed oblique-incidence and vertical-incidence night ionograms. K_p remained between 5+ and 5- . (See also the June 9, 1958 example of Morning and Afternoon Sequences in Section III-2)

CARTHAGE FEBRUARY 5, 1957

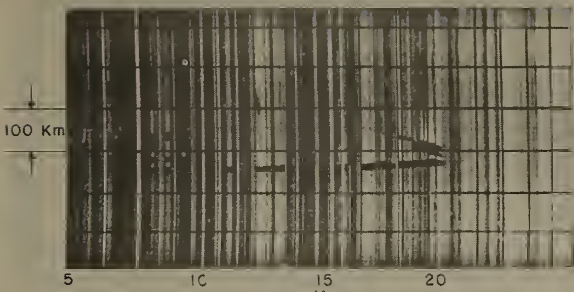
STERLING



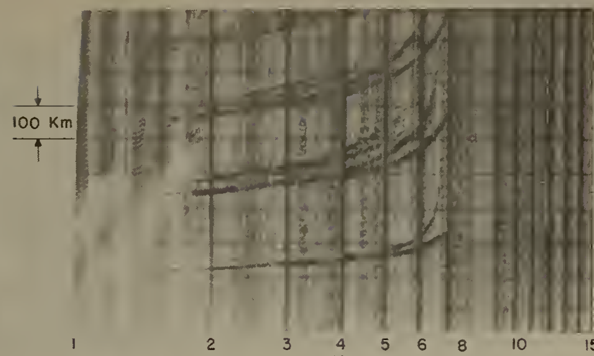
OBLIQUE VERTICAL

CARTHAGE FEBRUARY 5, 1957

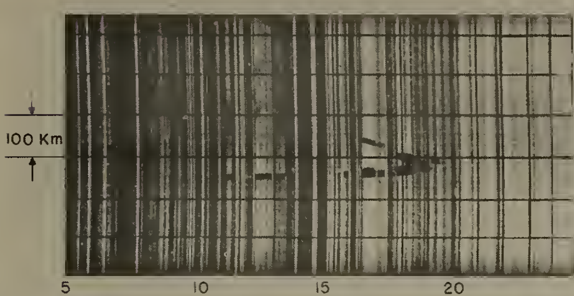
STERLING



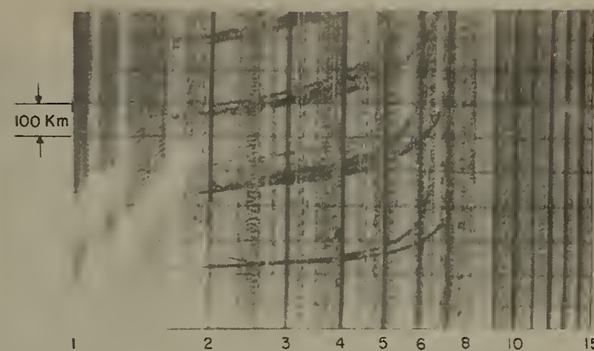
2032



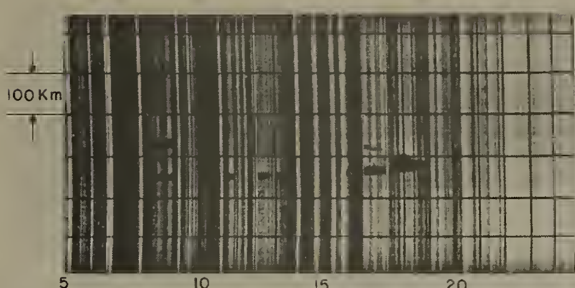
2032



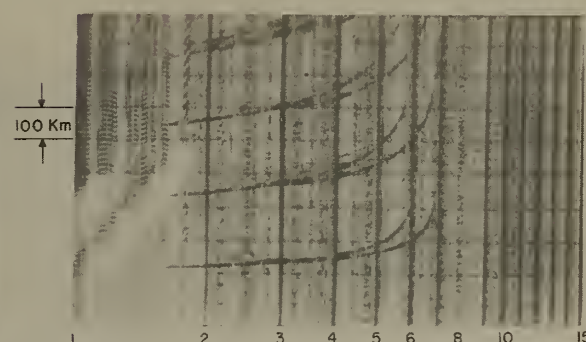
2040



2041



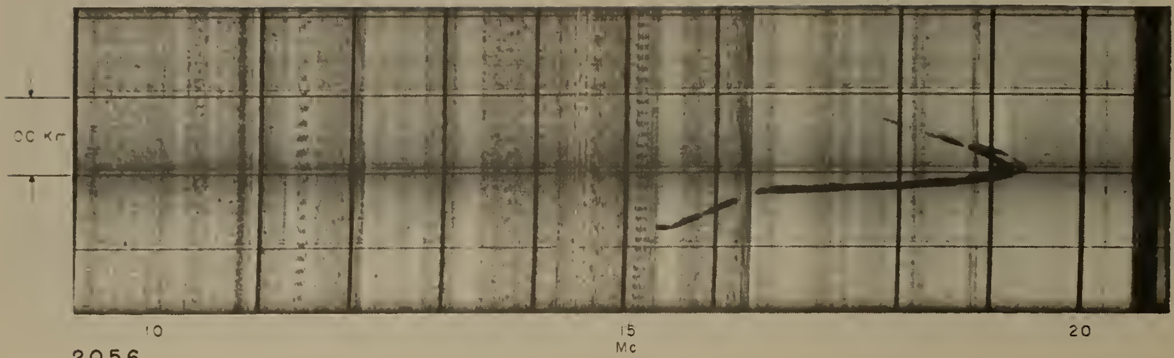
2047



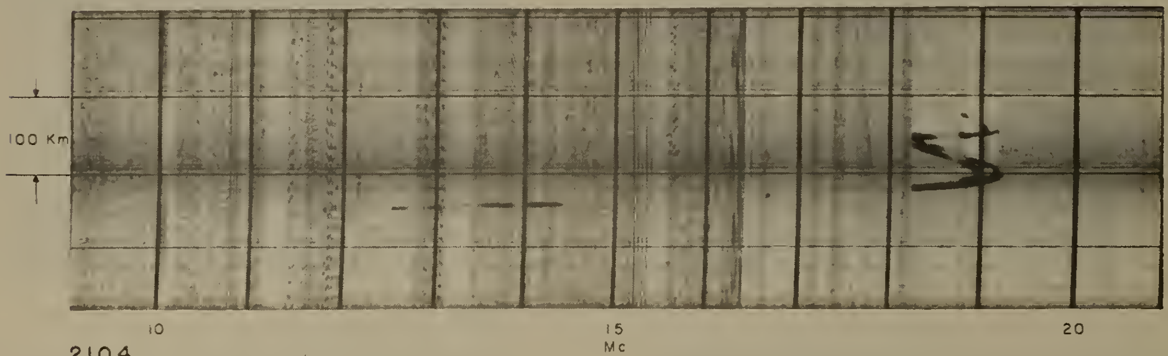
2047

OBLIQUE

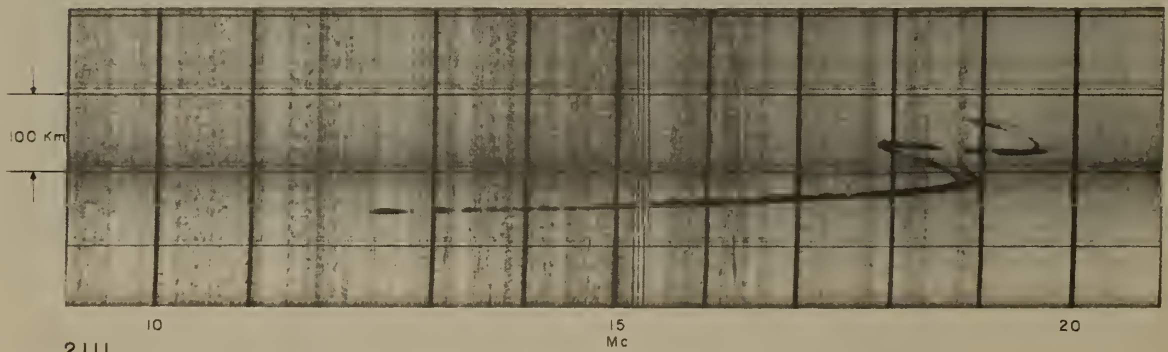
VERTICAL



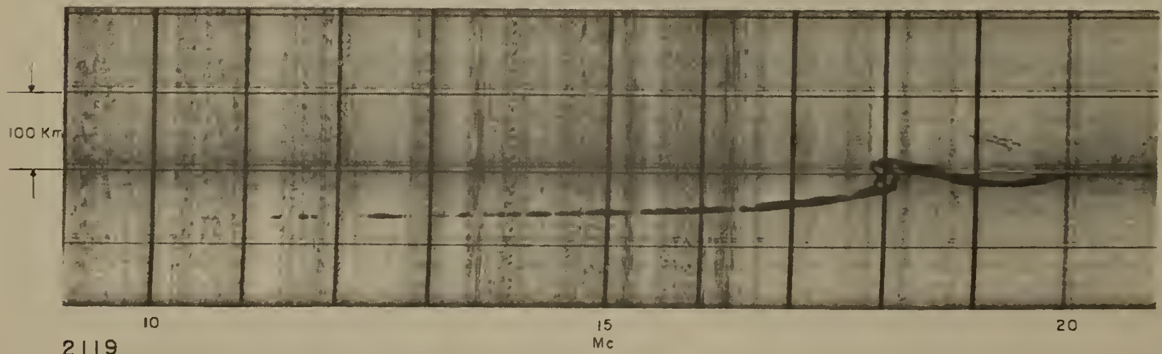
2056



2104

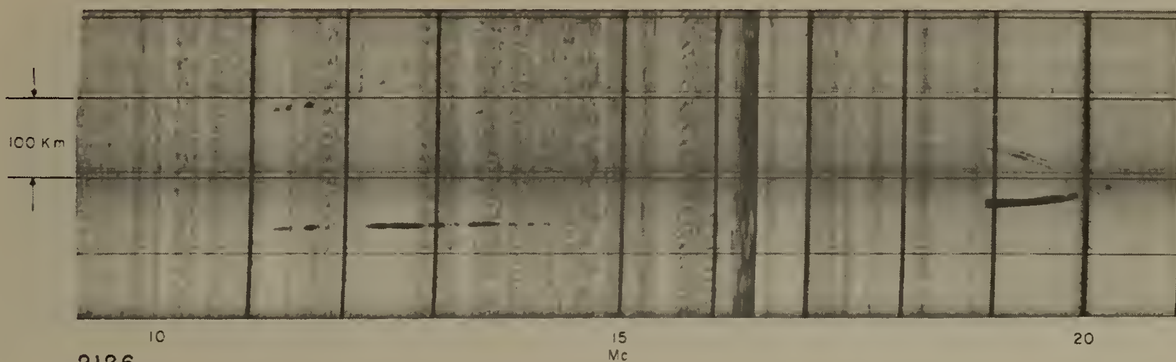


2111

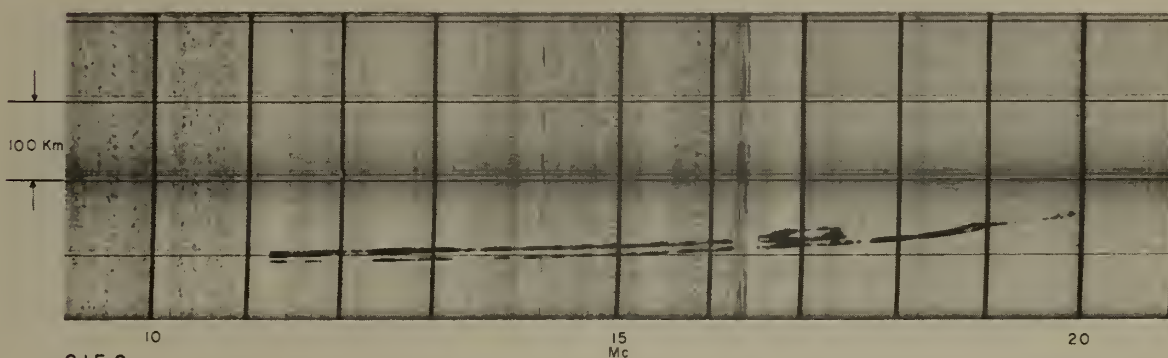


2119

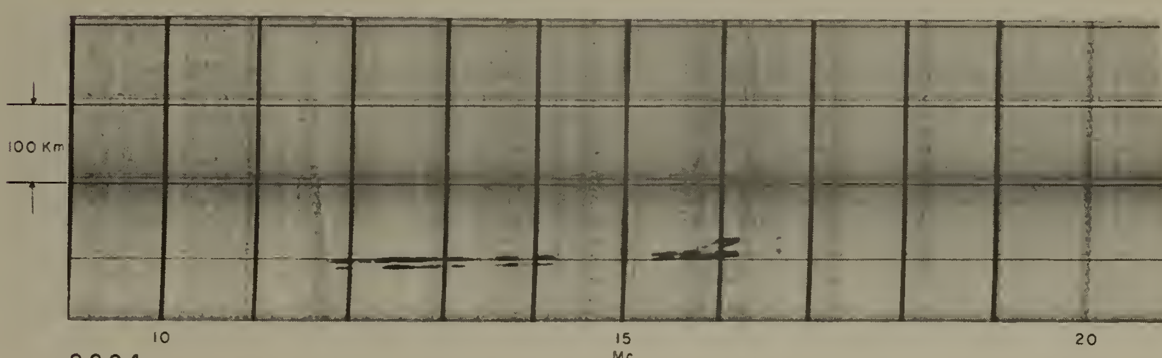
BOULDER JUNE 9, 1958



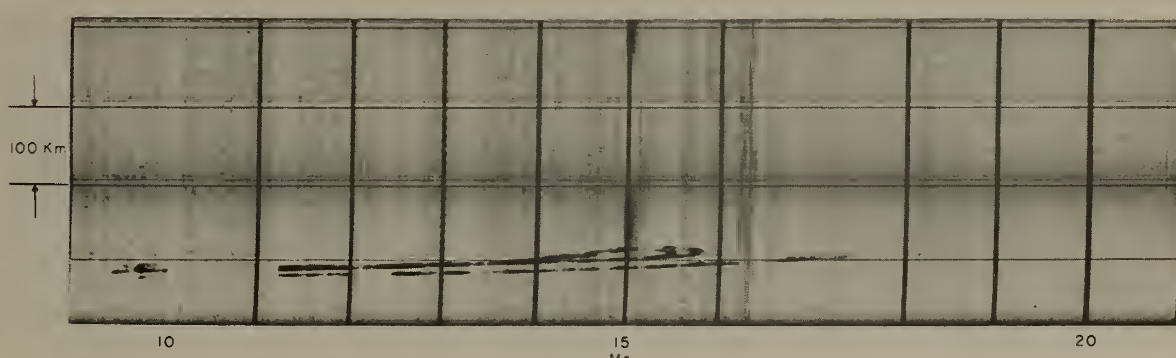
2126



2156

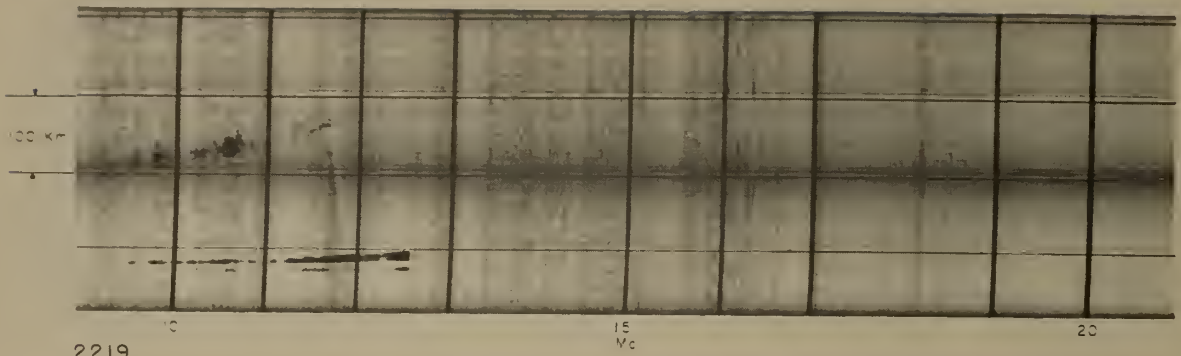


2204

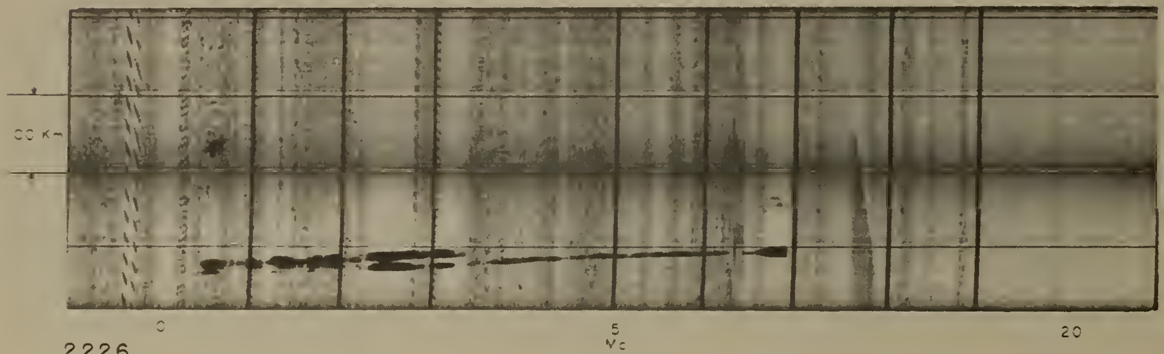


2211

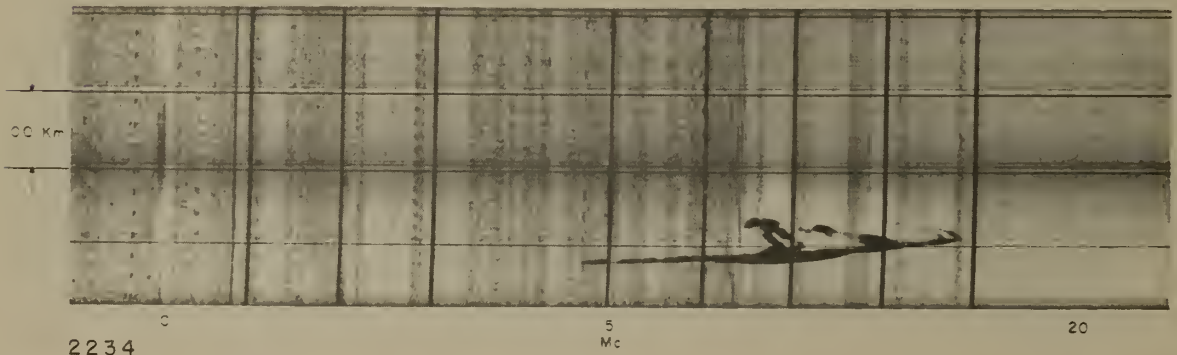
BOULDER JUNE 9, 1958



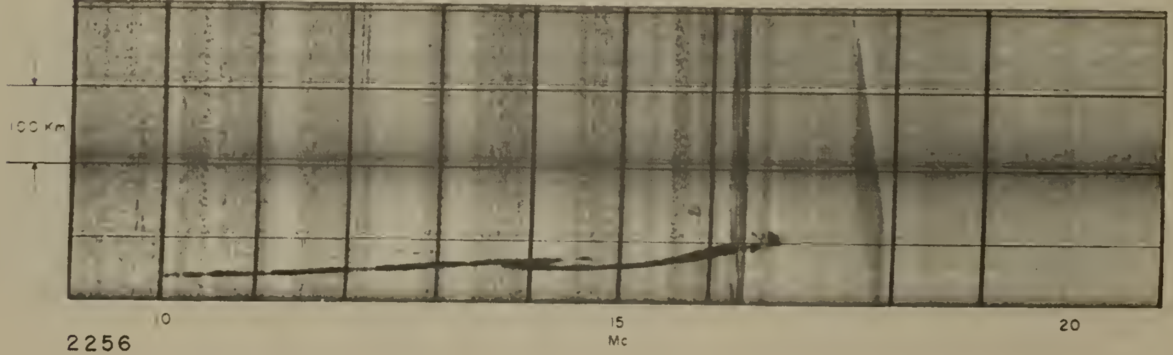
2219



2226

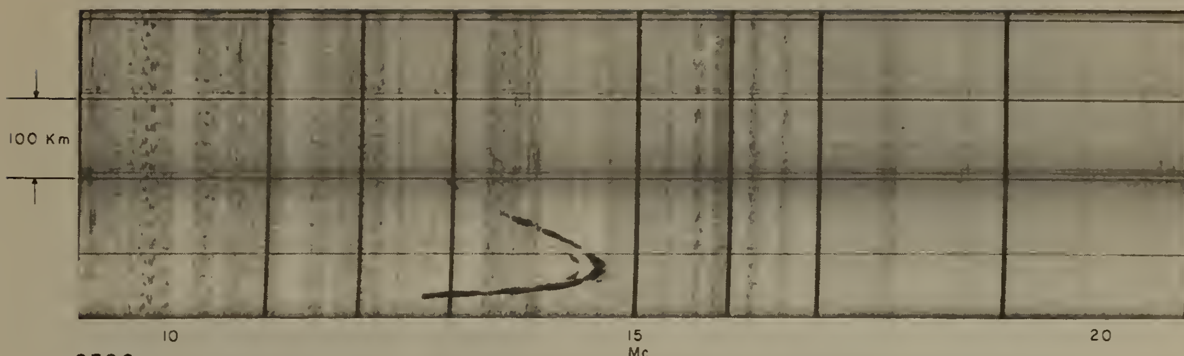


2234

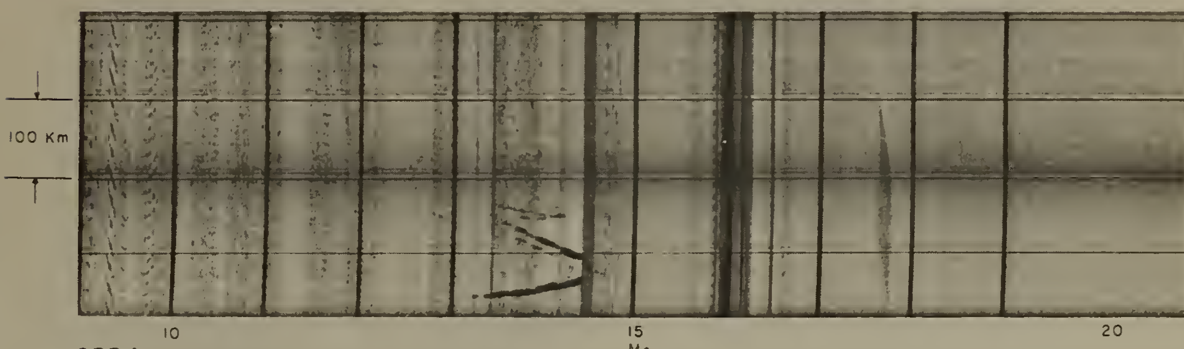


2256

BOULDER JUNE 9, 1958



2326



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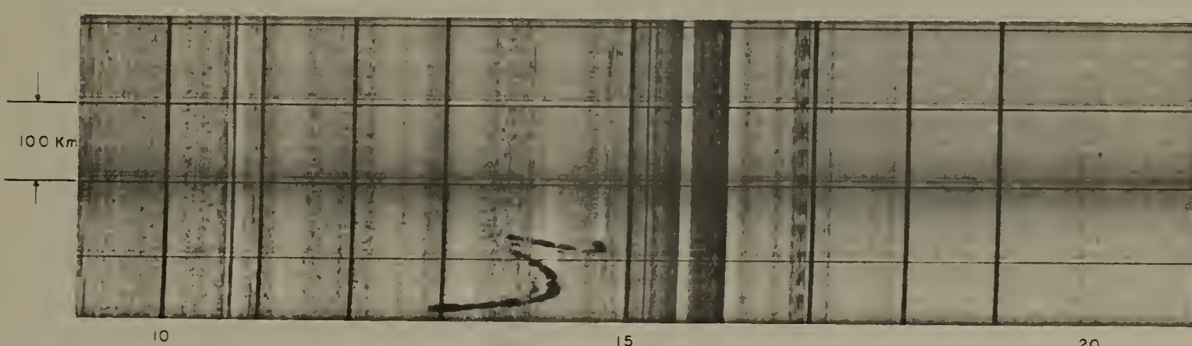

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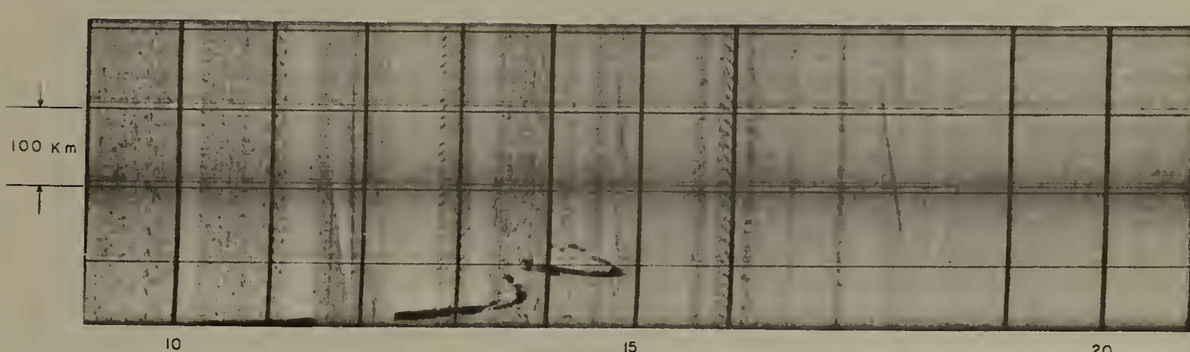
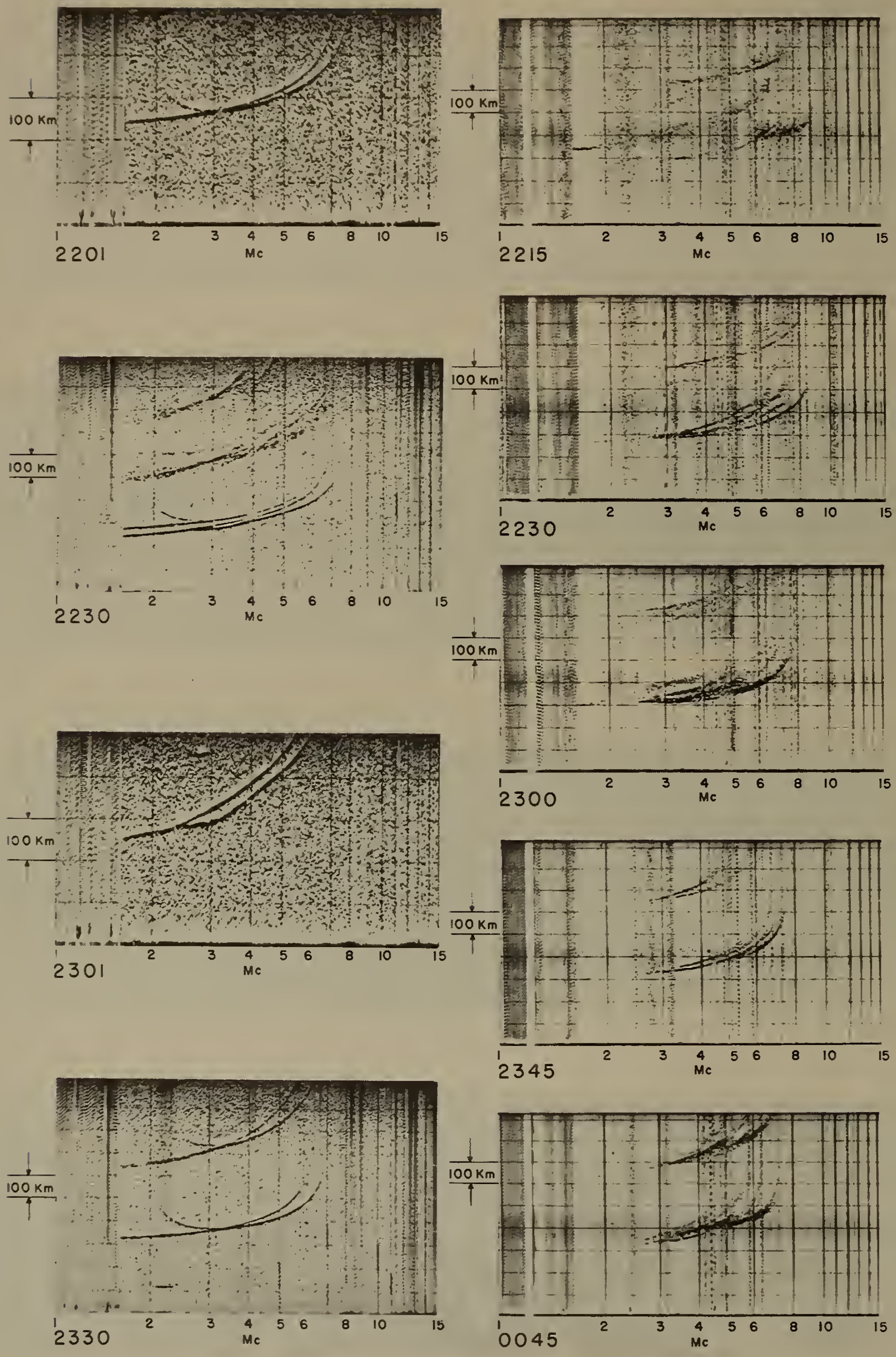


2349

BOULDER

WASHINGTON JUNE 9, 1958



VERTICAL

Sterling-Boulder
(Experimental)

Rarely Observed Ionograms

May 5, 1958

The appearance of the extraordinary component as a nose extension.

April 9, 1957

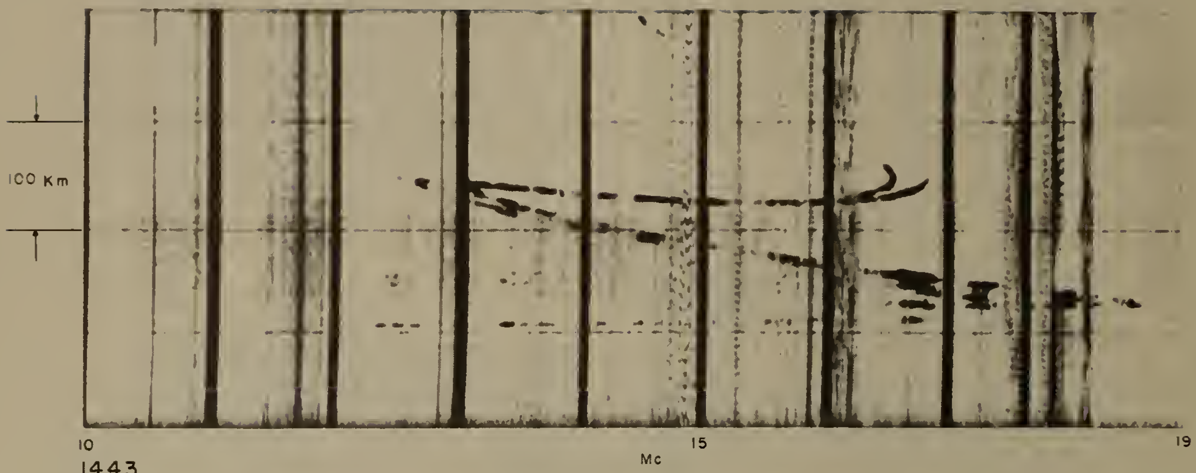
The rounded F2 nose may be attributed to the similarity between the vertical-incidence ionogram and the transmission curve.

August 2, 1956

August 30, 1957

The high-angle ray of the E mode is seldom seen on the 2400 km path.

BOULDER MAY 5, 1958



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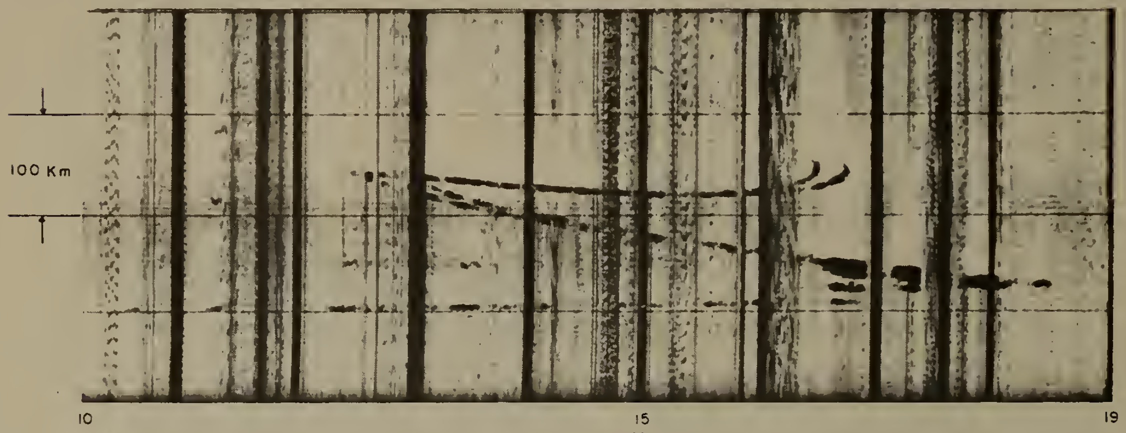

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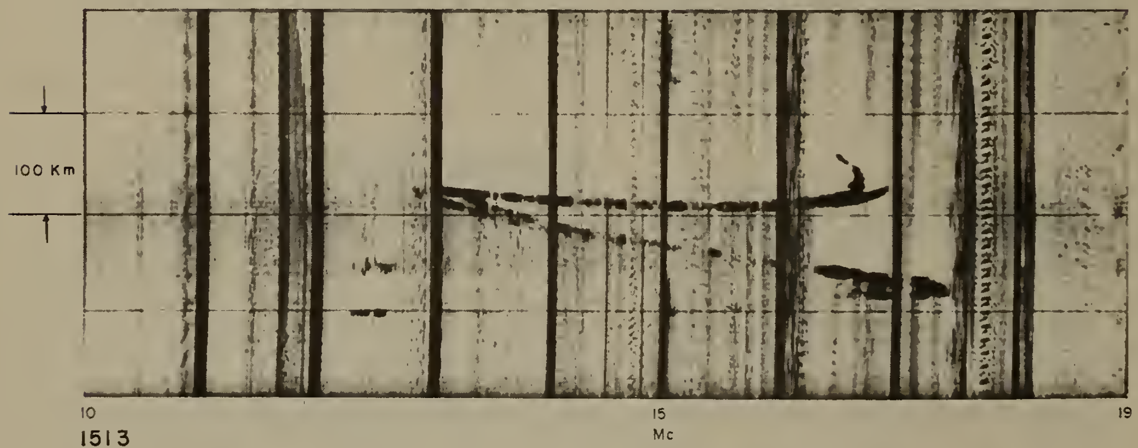
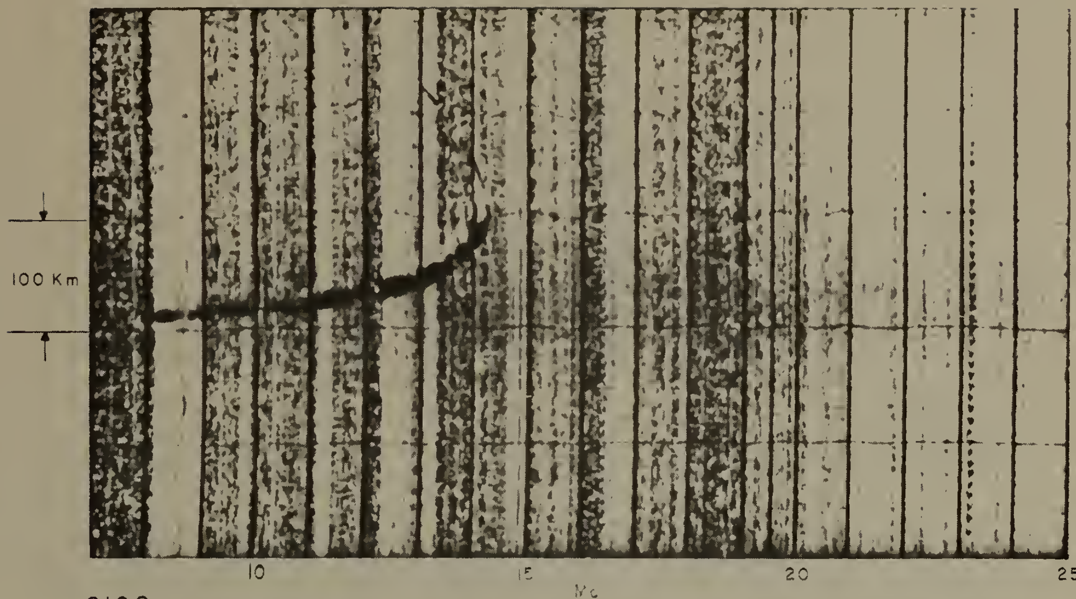


1513

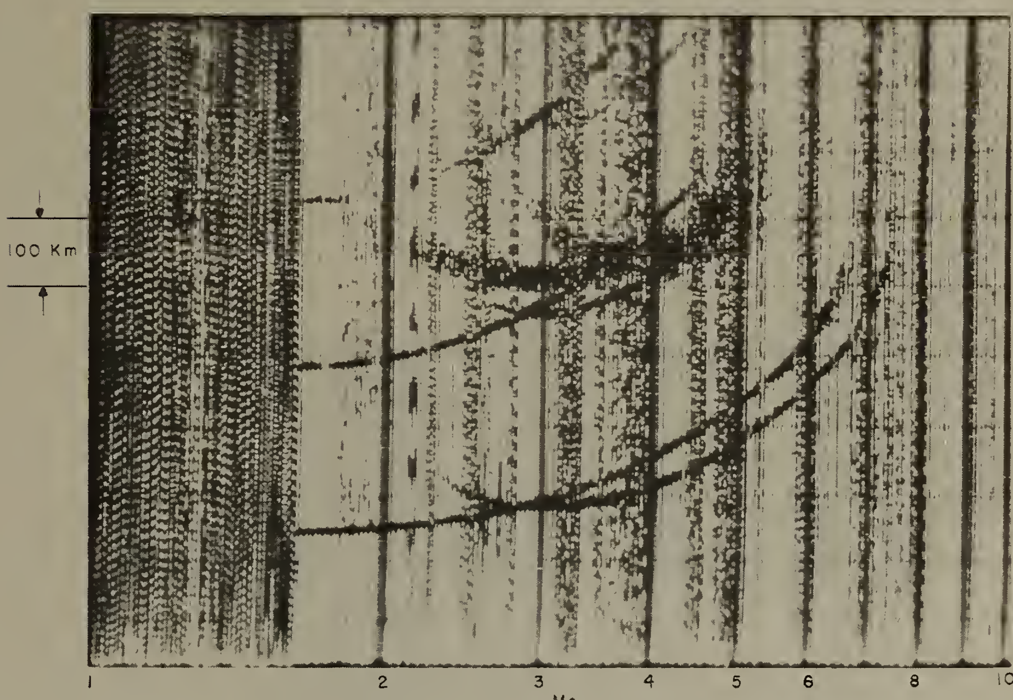
BOULDER APRIL 9, 1957



2109

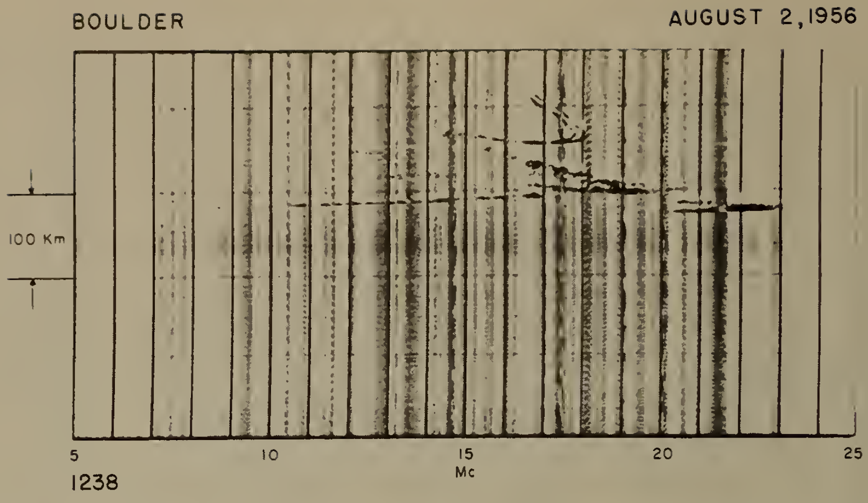
OBLIQUE

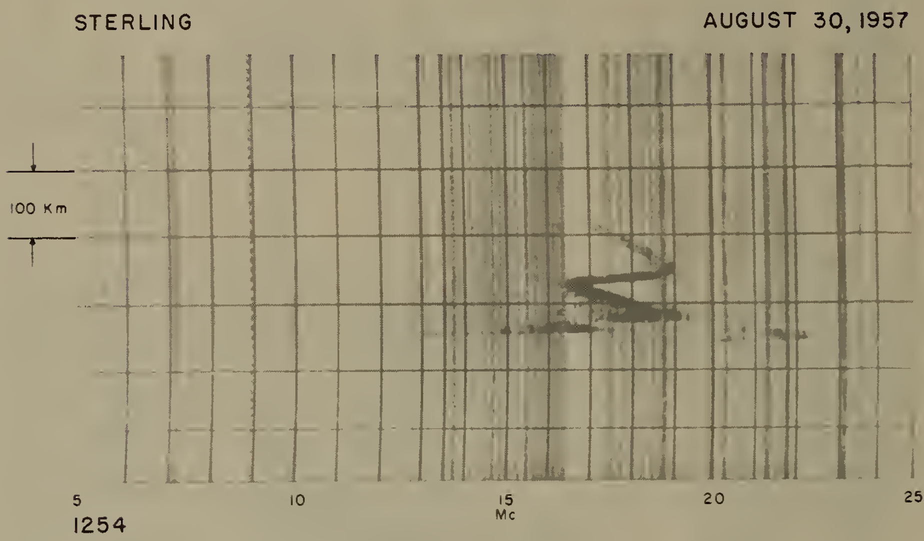
CARTHAGE

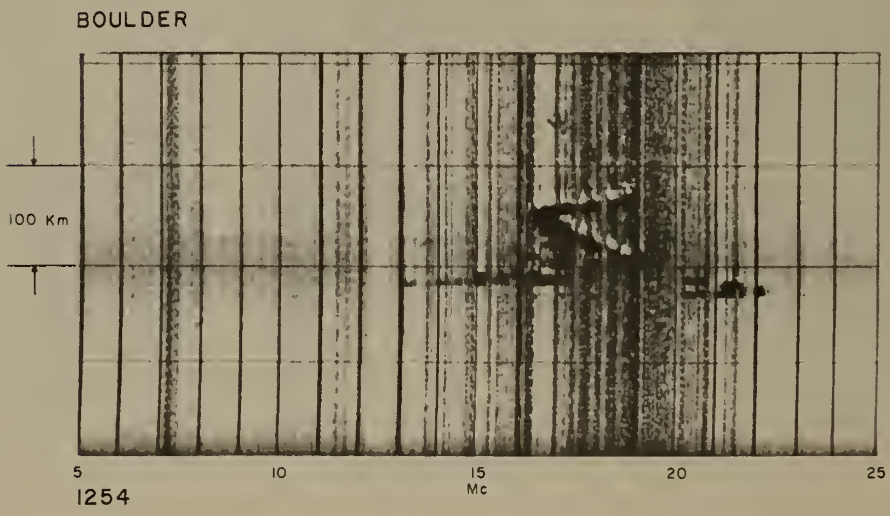


2109

VERTICAL


BOULDER
AUGUST 2, 1956
100 Km
5
10
15
20
25
Mc
1238


STERLING
AUGUST 30, 1957
100 Km
5
10
15
20
25
Mc
1254


BOULDER
100 Km
5
10
15
20
25
Mc
1254

Sterling-Boulder
(Experimental)

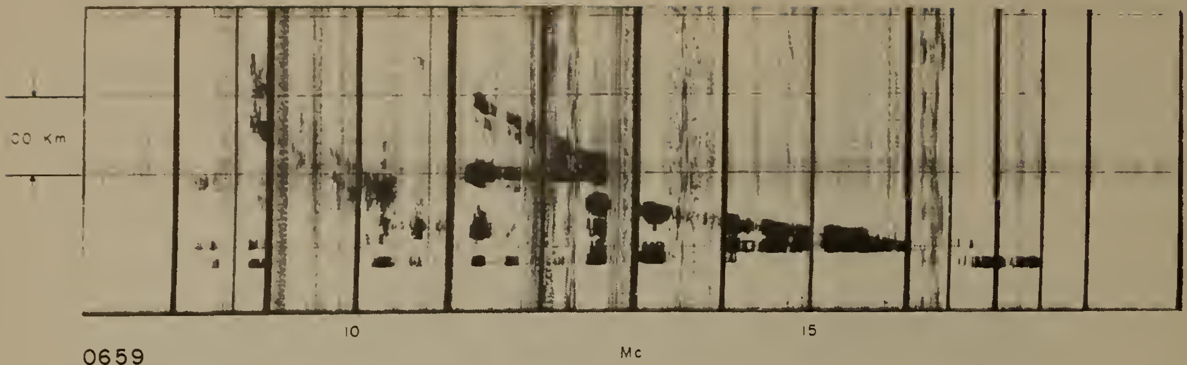
Equipment Effects

The June 24, 1958, 0659 and 0707 CST ionograms were received using 100 and 20 µs transmitted pulses respectively. The June 26, 1958, 1944 CST ionogram was received with every 10th transmitter pulse changed to 100 or 20 µs. The loss of detail with the longer pulse can be seen.

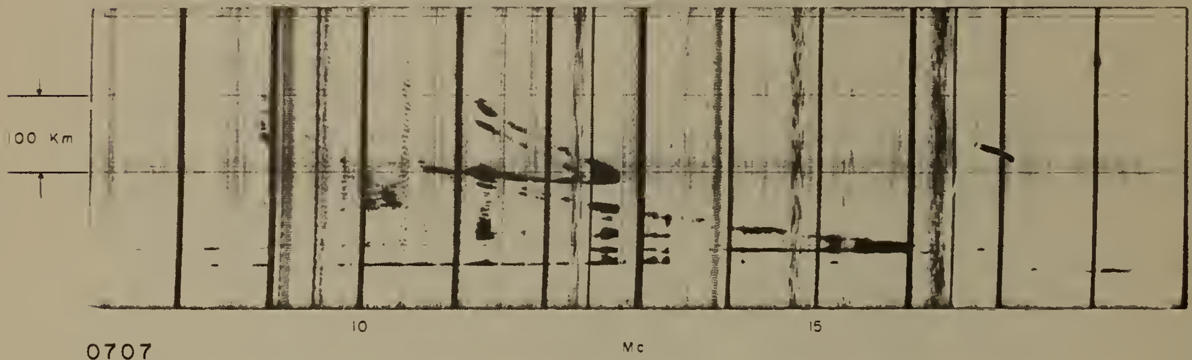
The top records on August 1, 1958 are those ordinarily received. The bottom records were taken simultaneously with large differentiation in the receiving system.

The 1323 CST ionogram of July 23, 1957 illustrates the effect of transmitter double pulsing. The parallel traces on the March 12, 1957 and April 23, 1957 ionograms may also be attributed to a deformed transmitter pulse.

BOULDER JUNE 24, 1958

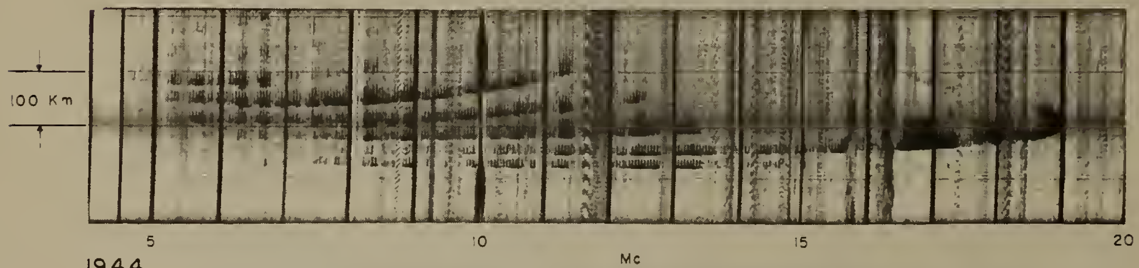


0659



0707

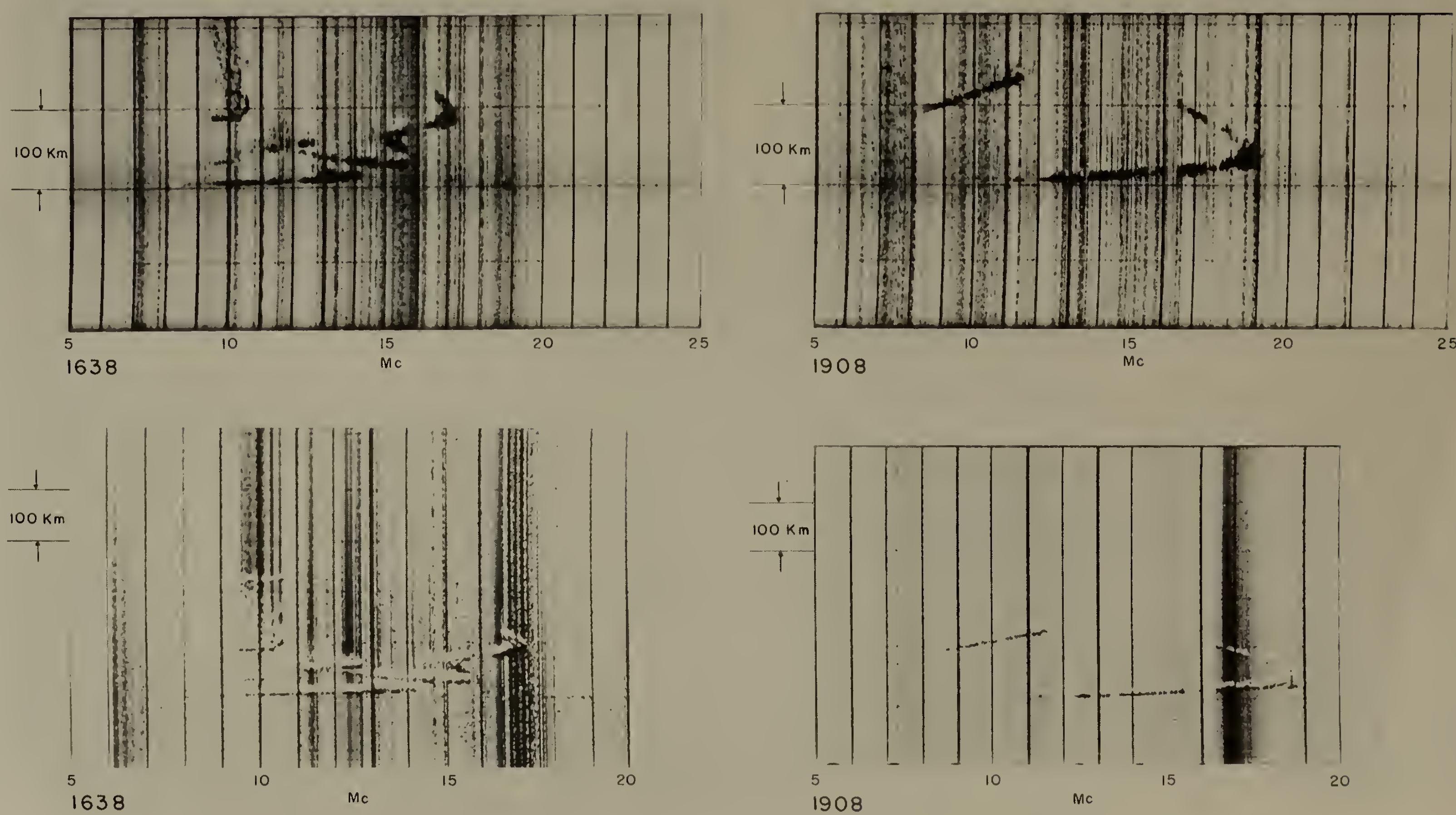
JUNE 26, 1958

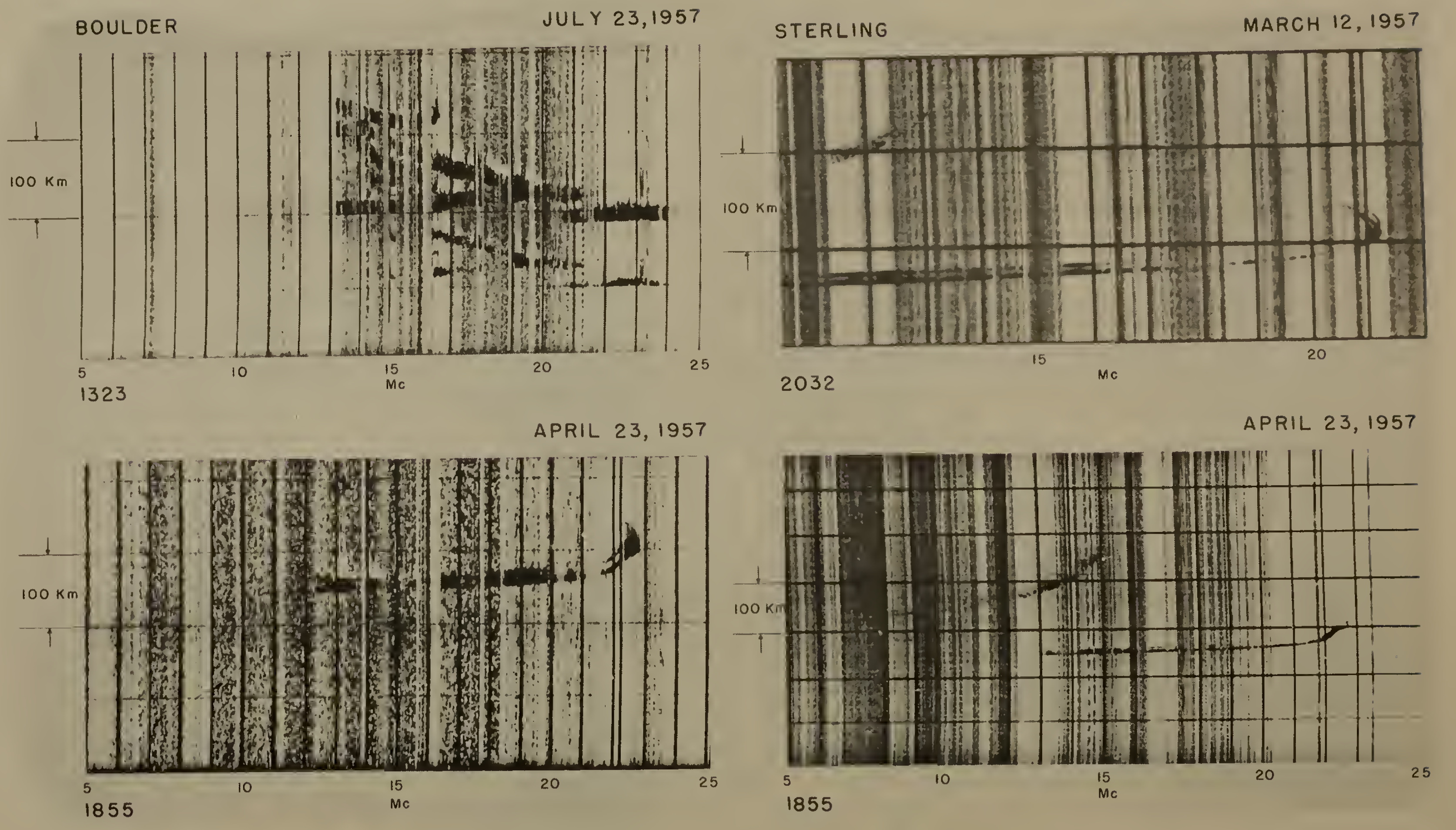


1944

BOULDER

AUGUST 1, 1958





BOULDER
JULY 23, 1957
100 Km
5
10
15
Mc
20
25
1323
STERLING
MARCH 12, 1957
100 Km
15
Mc
20
2032
APRIL 23, 1957
100 Km
5
10
15
Mc
20
25
1855
APRIL 23, 1957
100 Km
5
10
15
Mc
20
25
1855

Sterling-Boulder
(Experimental)

Fixed Frequency vs. Sweep Frequency

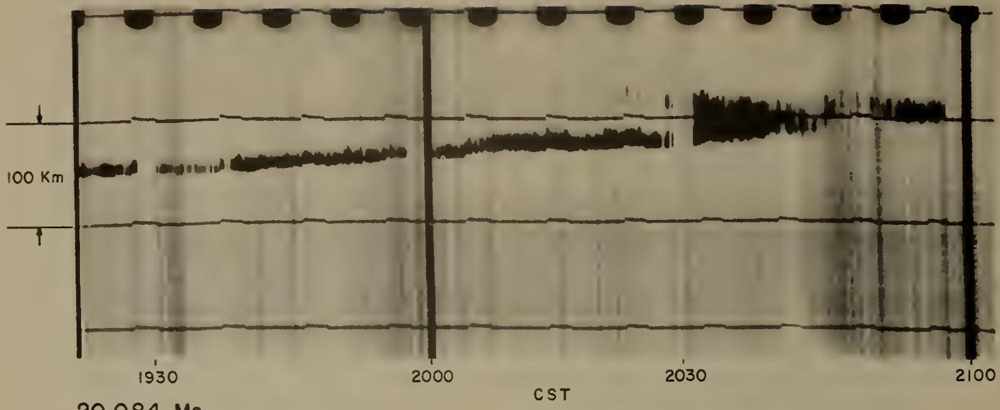
May 7, 1958

The first ionogram shows the pulse received on 20.084 Mc, from 1920 to 2100 CST. The following sweep-frequency ionograms were obtained during the same period. Both transmitters used a 25 μs pulse at a 25 pps repetition rate. The output of the fixed-frequency transmitter was about 200 kw.

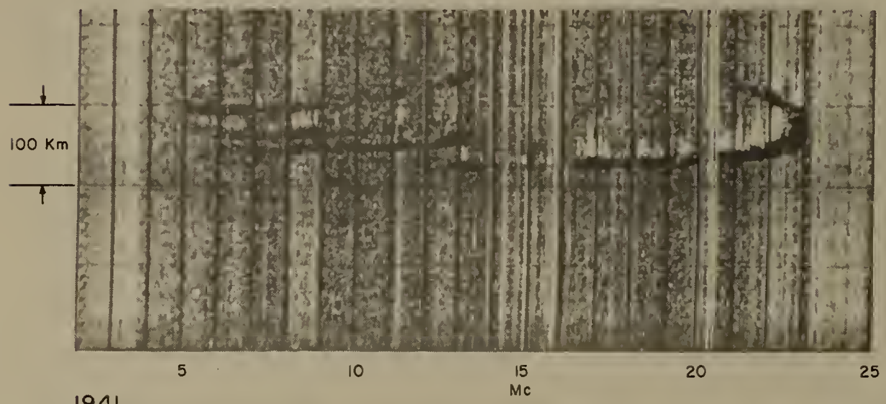
The hesitation of the F2 MUF at about 20 Mc appears as a nose extension on the fixed-frequency record.

BOULDER

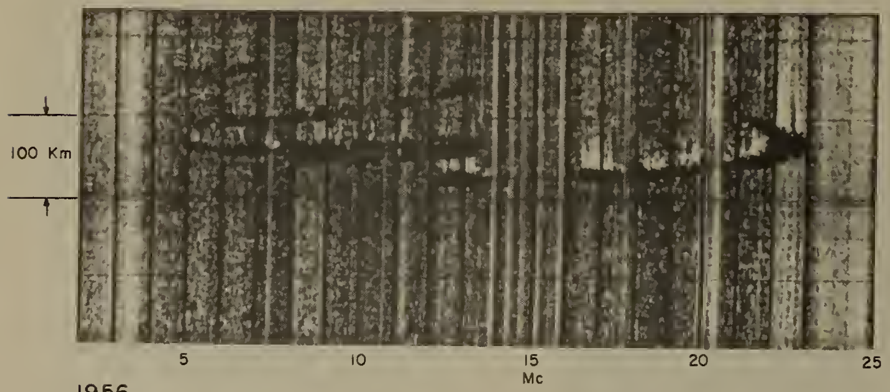
MAY 7, 1958



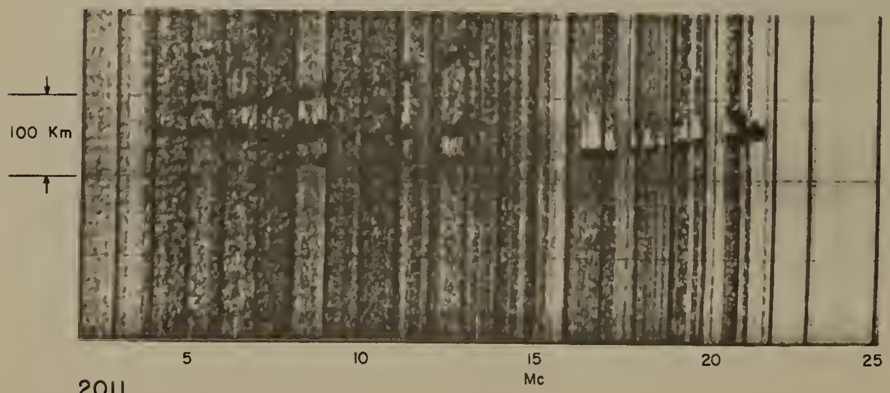
20.084 Mc



1941

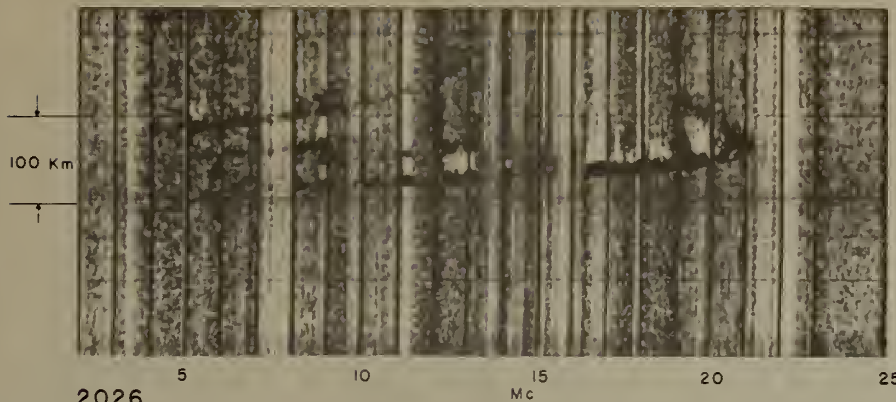


1956

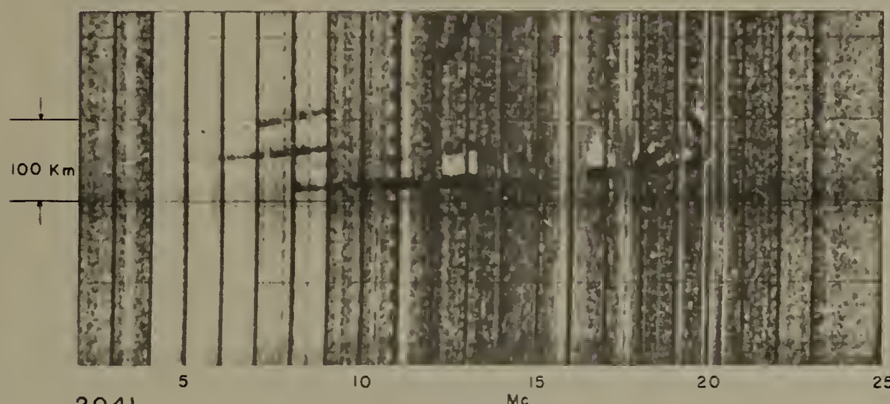


2011

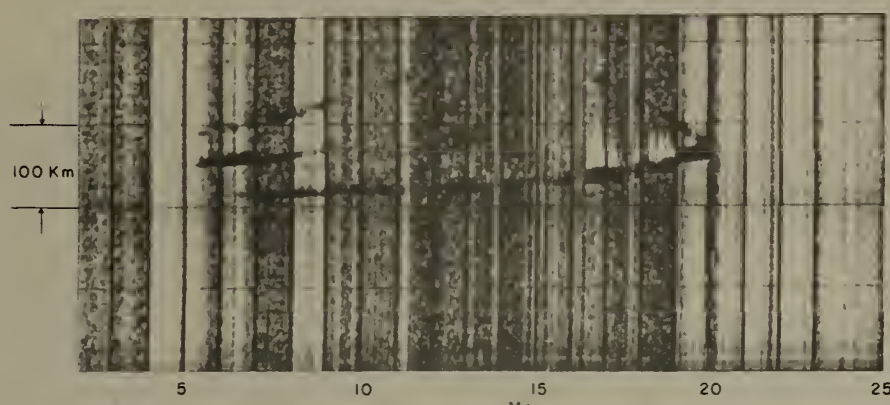
BOULDER MAY 7, 1958



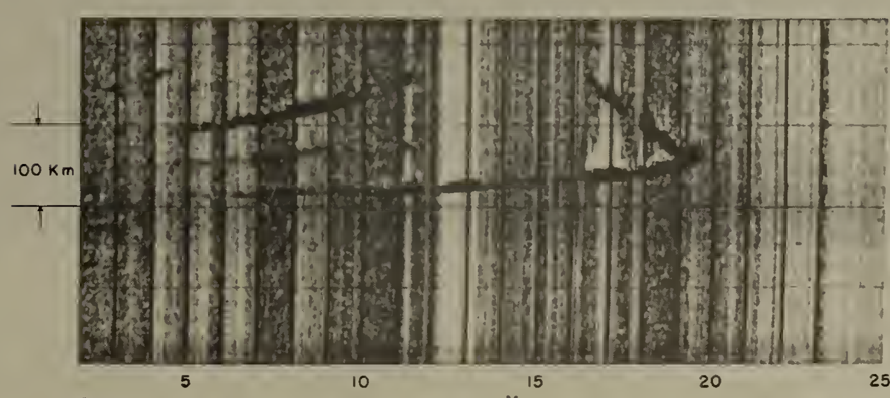
2026



2041



2056



2111

Sterling-Boulder
(Experimental)

A Sequence of A-scan Records Showing Field Strength Variations Near the MUF

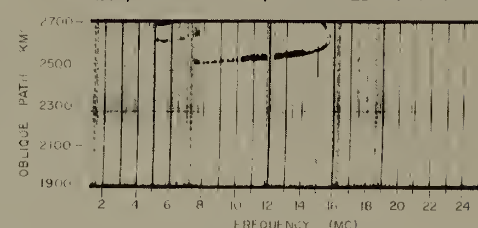
In addition to the time-delay studies, some attention has been given to received field strengths. Here is shown a series of A-scan records made at Boulder and the corresponding oblique-incidence ionograms. The frequency at which the A-scan records were made increases upward in each column and from left to right. These were made at the rate of $2\frac{1}{2}$ per second (or every .025 Mc). On each record, time delay increases toward the right. The pulse amplitudes — the scale is approximately linear — vary somewhat due to normal fading.

At frequencies greater than 14.8 Mc (near the top of the first column) the Pedersen ray first makes its appearance. At about 15.1 Mc (at the top of the second column) it shows two component pulses, the ordinary and the extraordinary modes. At about 15.3 Mc (near the top of the third column) similar slight separation of the O and X modes in the low-angle ray can be seen. Following the progression upward in the fourth column, as the low-angle and high-angle rays begin to overlap (just above 15.4 Mc) the pulse structure becomes complex; at 15.475 Mc the ordinary rays have combined and at 15.55 Mc only the extraordinary ray pulses are left. These have combined at about 15.625 Mc and have disappeared at 15.7 Mc.

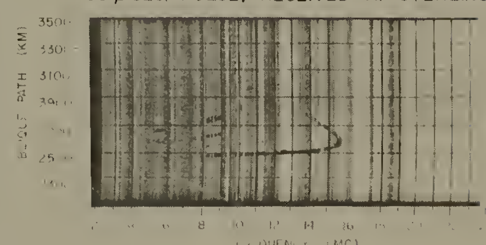
OBLIQUE INCIDENCE AMPLITUDES NEAR MUF

BOULDER – STERLING PATH (2370 KM)
JULY 16, 1957, 2054 CST

20 μ SEC PULSE, RECEIVED AT BOULDER



50 μ SEC. PULSE, RECEIVED AT STERLING



U. S. DEPARTMENT OF COMMERCE
Frederick H. Mueller, Secretary

NATIONAL BUREAU OF STANDARDS
A. V. Astin, Director

THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards at its major laboratories in Washington, D.C., and Boulder, Colorado, is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section carries out specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant publications, appears on the inside of the front cover.

WASHINGTON, D.C.

Electricity and Electronics. Resistance and Reactance. Electron Devices. Electrical Instruments. Magnetic Measurements. Dielectrics. Engineering Electronics. Electronic Instrumentation. Electrochemistry.

Optics and Metrology. Photometry and Colorimetry. Photographic Technology. Length. Engineering Metrology.

Heat. Temperature Physics. Thermodynamics. Cryogenic Physics. Rheology. Molecular Kinetics. Free Radicals Research.

Atomic and Radiation Physics. Spectroscopy. Radiometry. Mass Spectrometry. Solid State Physics. Electron Physics. Atomic Physics. Neutron Physics. Radiation Theory. Radioactivity. X-rays. High Energy Radiation. Nucleonic Instrumentation. Radiological Equipment.

Chemistry. Organic Coatings. Surface Chemistry. Organic Chemistry. Analytical Chemistry. Inorganic Chemistry. Electrodeposition. Molecular Structure and Properties of Gases. Physical Chemistry. Thermochemistry. Spectrochemistry. Pure Substances.

Mechanics. Sound. Mechanical Instruments. Fluid Mechanics. Engineering Mechanics. Mass and Scale. Capacity, Density, and Fluid Meters. Combustion Controls.

Organic and Fibrous Materials. Rubber. Textiles. Paper. Leather. Testing and Specifications. Polymer Structure. Plastics. Dental Research.

Metallurgy. Thermal Metallurgy. Chemical Metallurgy. Mechanical Metallurgy. Corrosion. Metal Physics.

Mineral Products. Engineering Ceramics. Glass. Refractories. Enameled Metals. Constitution and Microstructure.

Building Technology. Structural Engineering. Fire Protection. Air Conditioning, Heating, and Refrigeration. Floor, Roof, and Wall Coverings. Codes and Safety Standards. Heat Transfer. Concreting Materials.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics.

Data Processing Systems. SEAC Engineering Group. Components and Techniques. Digital Circuitry. Digital Systems. Analog Systems. Application Engineering.

• Office of Basic Instrumentation. • Office of Weights and Measures.

BOULDER, COLORADO

Cryogenic Engineering. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Gas Liquefaction.

Radio Propagation Physics. Upper Atmosphere Research. Ionospheric Research. Regular Propagation Services. Sun-Earth Relationships. VHF Research. Radio Warning Services. Airglow and Aurora. Radio Astronomy and Arctic Propagation.

Radio Propagation Engineering. Data Reduction Instrumentation. Modulation Research. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Propagation Obstacles Engineering. Radio-Meteorology. Lower Atmosphere Physics.

Radio Standards. High Frequency Electrical Standards. Radio Broadcast Service. High Frequency Impedance Standards. Electronic Calibration Center. Microwave Physics. Microwave Circuit Standards.

Radio Communication and Systems. Low Frequency and Very Low Frequency Research. High Frequency and Very High Frequency Research. Ultra High Frequency and Super High Frequency Research. Modulation Research. Antenna Research. Navigation Systems. Systems Analysis. Field Operations.

NBS